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ECOLOGICAL INTERACTIONS IN THE RIPARIAN ZONE: A SYSTEMS ANALYSIS, SIMULATION MODEL AND RESEARCH REVIEW FOR THE SAVAL RANCH RESEARCH AND EVALUATION PROJECT

by

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FOREWORD

The contents of this report are a product of two workshops (held March, 1983 and March, 1984), and the efforts of many people. The participants listed on the following pages provided the insight and information required to both formulate a preliminary simulation model of the riparian system, and review riparian zone research activities.

During the first workshop, participant contributions were stimulated, organized and eventually converted into computer code by four members of the Saval Project who acted as workshop facilitators: Gary Back, Debbie Palmquist, Steve Loomis and Waive Stager. These four scientists did a superb job in spite of three major constraints: they were running their first workshop, they had only three and one-half days to accomplish what is normally done in five days, and they were required to debug a complex model on Apple microcomputers, a task normally reserved for larger systems.

We also acknowledge with thanks the hard work contributed by other scientists, both within and outside the Saval Project, at the two workshops.

We are grateful to Peter Lent for his continuing efforts to maintain the direction of the project and sharpen its interdisciplinary focus. Thanks are also due to the Saval Ranch owners and managers, who have made this project possible.

Finally, we thank Jean Zdenek of ESSA Ltd. for producing this report so speedily (while still maintaining her high standard of excellence), and to Sharon Galenzoski for preparing the figures.

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1.0 INTRODUCTION

The integration component of the Saval Project has focused on two primary objectives:

1) identifying the hypotheses that should be tested to evaluate the impacts of the Saval Ranch Management Plan; and

2) providing expertise and tools to help integrate the results of Saval Ranch research.

Since September, 1981, a series of tasks have been completed to help accomplish these objectives:

1) November, 1981 - An intensive 5-day meeting was held, with thirty participants and five workshop facilitators. The group constructed an initial model of the entire Saval Ranch, including livestock, economics, soils, vegetation, hydrology and wildlife components.

2) November, 1981 - January, 1982 - Substantial documentation and model refinement occurred after the first workshop. Two microcomputer models were constructed to increase understanding of important parts of the range ecosystem: relationships between vegetation dynamics and sage grouse populations, and vegetation-hydrology interactions.

3) January, 1982 - A second workshop lasted three days and involved a smaller number of participants and staff. Research plans for the 1982 field season were reviewed in light of the hypotheses identified at the first workshop.

4) June, 1982 - Saval Project personnel participated in a week-long training session, in which they learned to construct simulation models on microcomputers. The models addressed problems in hydrology, water quality, fisheries and range management.

5) November, 1982 - A two-day meeting was held to review all aspects of the Saval Project; outside experts from BLM, UNR and other agencies were invited to critique research activities. Following the meeting, a mini-workshop was held with five people, who constructed a model of bird species richness in riparian areas, and reviewed current research.

The November, 1982 meeting highlighted the need to establish an "in-house" capability to review research, conduct workshops and construct integrative simulation models. Also, it became evident that ecological change within the riparian zone of range systems was of major scientific and applied interest. Therefore, a workshop was held March 15 - 18, 1983 with the following two objectives:

1) to train four Saval Project scientists as an integration team, with skills in facilitating workshops and building computer simulation models; and

2) to construct a computer simulation model of a riparian zone as a focus for discussing interdisciplinary research on interactions between fisheries, hydrology, vegetation, cattle and hay production.

Sections 2 to 5 of this report describe the results of that workshop. It should be stressed that unless otherwise stated, the functional relationships described therein are based on the professional judgement of participants, and not on actual data.

It is unfortunate there was not sufficient time to get the simulation model working during the workshop. However, by making explicit hypotheses about the riparian system, participants gained a firm perspective from which to review the relevance and quality of ongoing research.

The conceptual model developed at the March, 1983 workshop formed the basis for a second workshop on the riparian zone held March 27 - 29, 1984. Based on the conceptual model, the workshop staff and participants created a set of impact hypotheses, describing the direct and indirect effects of management activities on important components of the riparian system. Existing and potential research activities were then evaluated with respect to these hypotheses, as described in Sections 6 and 7 of this report.

A draft of Sections 2 to 7 was circulated to participants in June, 1984, and their comments have been incorporated into this final report. Also included in this report are the results of a riparian system simulation model (Section 8), constructed from the conceptual model described in Chapters 2 to 5*. Though the model's structure is quite simple, and many of its assumptions uncertain, the results are qualitatively reasonable and interesting. To facilitate gaming with the model and further improvement of functional relationships, we have included a detailed user manual (Appendices B to E), a documented program listing (Appendix F), and a program diskette (inside back cover).

---

* Readers especially interested in modelling may prefer to read Chapter 8 directly after Chapter 5.

2.0 BOUNDING

At the beginning of the workshop, participants were led through an exercise called bounding. The objective of this exercise is to define the problem in such a way that the workshop discussions and simulation model remain relevant to the problems at hand, and do not descend into a horrendously complex morass. To accomplish this objective, participants describe the feasible management alternatives, or actions, and the measures (called indicators) used to evaluate the effects of such actions on the biological/physical/economic system. The system to be simulated is further defined by placing the actions and indicators in a manageable spatial and temporal framework.

2.1 Actions and Indicators

In the context of riparian zones on semi-arid rangelands, actions are the feasible human interventions which can alter the characteristics and productivity of vegetation, the availability of water, and the distribution and intensity of cattle grazing.

The actions and indicators identified at the workshop were divided into three categories (Table 2.1), each being representative of a definable subsystem. Note that the indicators are used to evaluate the effects of all actions, not only those implemented within the same subsystem (e.g., effects of wood cutting on fish biomass). Not all identified actions and indicators were included in the preliminary model constructed at the workshop.

2.2 Space

Two issues made it difficult to define a spatial representation of the system. First, many processes outside the riparian zone affect conditions within it, which makes the choice of a spatial boundary awkward. Second, there are trade offs involved in deciding

Table 2.1: List of actions and indicators.

ACTIONS	INDICATORS
1. Vegetation/Wildlife	
- haying	- forage for cattle* (lbs/a; #a)
- fertilization	
- phreatophyte control	- forage for wildlife* (lbs/a; #a)
- wood cutting	- hay (tons $\cdot$ ac^{-1} $\cdot$ yr^{-1})
- chemical spraying	- % cover (herbaceous, shrub, tree)
- meadow renovation (e.g. brush removal)	- species richness of non-game birds
- irrigation	
2. Hydrology/Fish	
- beaver control	- biomass of fish (lbs/a; total by species)
- build dams	- catch/effort (#/hour)
- fishing	- sediment load
- stocking fish	- water quality indicators: water temperature, pH, turbidity, macro-invertebrates (presence/absence)
	- percent bank stability
3. Livestock/Economics	
- cattle grazing (# by season, % utilization)	- cattle weight gain (lbs/year)
- road construction	- cattle sales ($ by type)
- recreational development	- value of recreation days ($)
- residential development	- sale (or cost) of hay ($)
- mining	- cost of protein supplement
- actions affecting distribution: fencing, holding, salting/water development, riding	

---

*by 7 vegetation types

to model a specific creek or a generic one. Real systems offer real data, but they also have particular quirks which limit the generality of models simulating them.

Eventually, it was decided to model a generic system (appropriately christened Generic Creek). The system was considered to extend laterally to the edge of the floodplain, which represents the potential limit of the riparian zone (Figure 2.1). Longitudinally, the spatial limits were defined as proceeding from the sources of Generic Creek (headwater tributaries, springs, seeps, ephemeral and intermediate tributaries) through a grazing allotment and associated hay meadows, to the point where Generic Creek meets Generic River.

This overall area was then subdivided into three zones which differ substantively in hydrological characteristics, vegetation composition, and the actions that can potentially be implemented: a mountain zone, an alluvial zone, and a hay meadow. The hay meadow zone was further subdivided into bank and non-bank (floodplain) areas. This spatial resolution recognizes large differences in biophysical characteristics while maintaining the simplicity of only a few zones.

2.3 Time

A dynamic simulation model requires a time horizon over which model projections are of interest, and a time step over which the change in value of the state variables will be calculated and displayed. It was agreed that most of the actions under consideration would cause changes within 10 - 20 years, and 20 years therefore formed the time horizon.

For displaying the values of state variables, the group chose a basic time step of one year. It was recognized, however, that the model would need to proceed in shorter time steps to properly simulate some of the system's interactions and behavior.

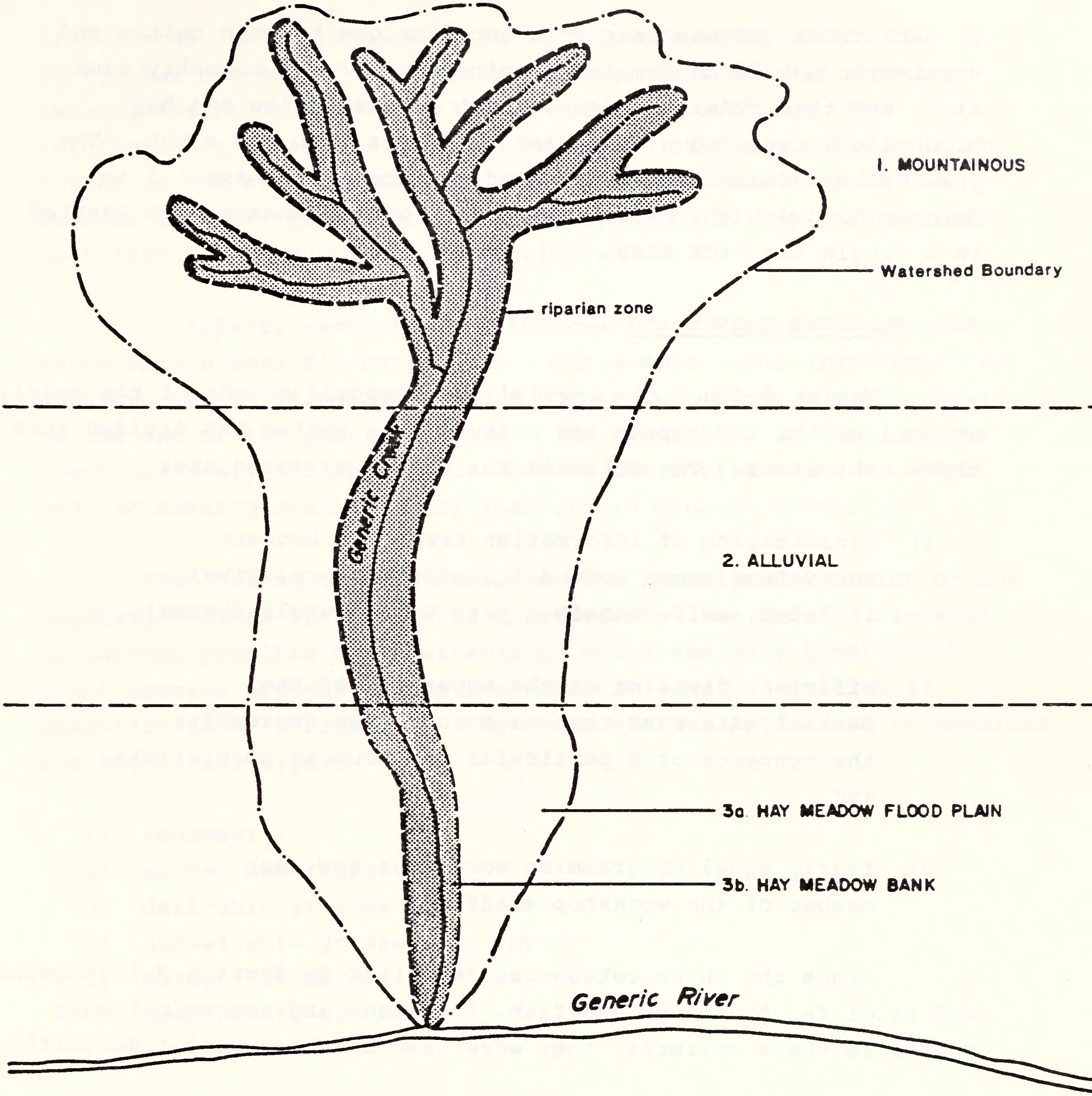


Figure 2.1: Spatial representation of riparian zone within model.

In particular, it was felt that interactions between cattle and vegetation should be simulated using a weekly or biweekly time step, and that other processes (such as streamflow and hay production) required a time step no longer than one month. The year to be modelled was considered to extend from April 1 to October 31, with the overall effect of winter changes represented in a single big time step.

2.4 Submodel Definition

Having defined the spatial and temporal bounds of the model, as well as the key inputs and outputs, the system was divided into three subsystems. The criteria for proper division are:

1) minimization of information transfers between subsystems (each submodel simulates a relatively isolated, self-contained part of the whole system);

2) efficient division of the expertise of the participants such that each subsystem represents the concerns of a particular subgroup of specialists; and

3) fairly equal programming workloads for each member of the workshop staff.

Since the three categories described in Section 2.1 (vegetation and wildlife, hydrology and fish, livestock and economics) best fulfilled these criteria, they were used as the submodel definitions.

2.5 Looking Outward

The purpose of the looking outward exercise is to define the pieces of information a particular subsystem requires from all other subsystems in order to predict how that subsystem will behave dynamically. This is a qualitatively different question than the traditional, which requires list of "factors which affect" a particular component of a system. The product of this exercise is an interaction matrix, with the columns specifying what information a subsystem requires from each of the other subsystems listed on the rows (Table 2.2). The diagonals are crossed out because those represent the internal dynamics of each subsystem, a task left to the subgroups to consider.

In effect, each piece of information listed in the matrix represents a specific hypothesis. For example, the hydrology/fish subgroup stated it needed percent herbaceous, shrub and tree cover at the end of the grazing season. The hypothesis is that percent cover has a significant effect on both the infiltration of water and the shading available for fish within Generic Creek.

The looking outward exercise also forced a definition of the vegetation types that would be considered in the model. Since it is neither possible nor desirable to model the many hundreds of plant species present within the riparian zone, a functional classification is required. The group eventually decided to consider six vegetation types:

1) legumes;
2) sedges and rushes;
3) desirable grasses and forbs;
4) undesirable grasses and forbs;
5) mesophytic shrubs; and
6) hydrophytic shrubs.

Table 2.2: Looking outward matrix.

FROM \ TO	HYDROLOGY/FISH	VEGETATION/WILDLIFE	CATTLE/ECONOMICS
HYDROLOGY/ FISH		- streamflow (a · ft/ month for April to August) - depth to water table (ft, for April to August) - sediment load (tons/ year) at upper and lower end of hay meadow - precipitation (inches/month) - mean maximum daily temperature/month	- fishermen effort (# days)
VEGETATION/ WILDLIFE	- % herbaceous, shrub and tree cover at end of grazing season		- % protein content of hay - hay produced (tons) - forage (lbs/a) by vegetation class and spatial unit - rate of growth of forage (%/month) by vegetation class and spatial unit
CATTLE/ ECONOMICS	- % utilization by vegetation class and spatial unit - # cattle use months in each spatial unit - first week of grazing (by spatial unit)	- % utilization by vegetation class and spatial unit - # cattle use months in each spatial unit	

3.0 VEGETATION AND WILDLIFE SUBMODEL

3.1 Model Structure

The vegetation/wildlife submodel consists of the following three components (Figure 3.1):

a) responses of plants to changes in water availability, water table depth, temperature, nutrients, and grazing;

b) hay production in the meadow spatial unit; and

c) changes in non-game bird habitat, and stream shading for fish.

The model operates on a yearly time step overall, but performs monthly calculations within each year to compute changes in vegetation (Figure 3.2). During the grazing period, cattle-vegetation interactions are handled on a weekly time step, within the cattle/economics submodel. The vegetation/wildlife submodel passes to the cattle/economics submodel the information required for grazing period computations.

3.2 Forage Production

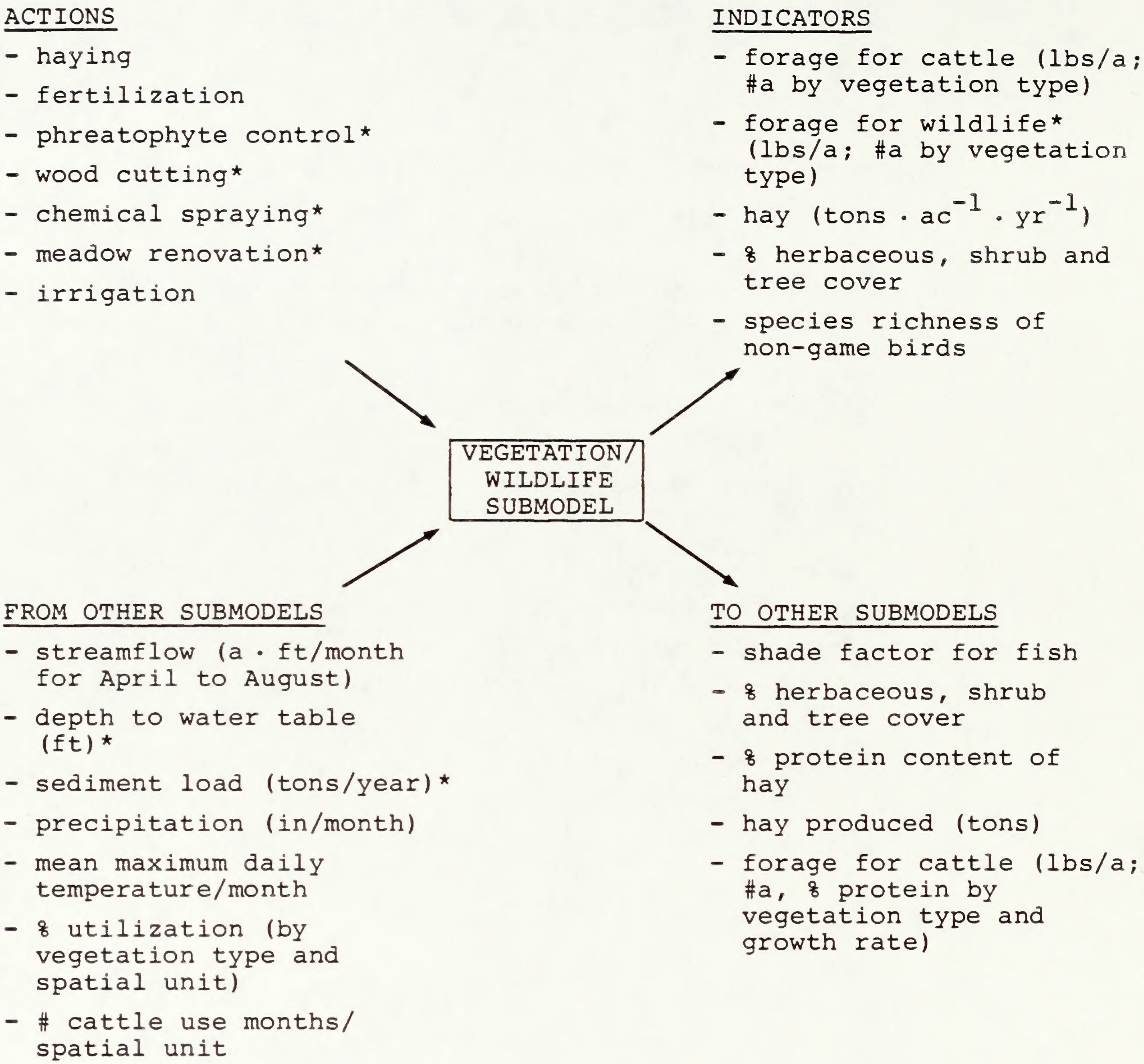
During grazing periods, the dynamics of vegetation biomass are handled by the cattle/economics submodel. At other times, the biomass of vegetation changes each month according to the following equation:

$$BA_{i,j,m} = BA_{i,j,m-1} * (1 + PG_{i,j,m} - ML_{i}) \qquad (3.1)$$

where,

BA = biomass of vegetation (lbs/a) (constrained to be < 5000);

PG = monthly growth rate of biomass;



ACTIONS

- haying
- fertilization
- phreatophyte control*
- wood cutting*
- chemical spraying*
- meadow renovation*
- irrigation

INDICATORS

- forage for cattle (lbs/a; #a by vegetation type)
- forage for wildlife* (lbs/a; #a by vegetation type)
- hay (tons · ac^{-1} · yr^{-1})
- % herbaceous, shrub and tree cover
- species richness of non-game birds

FROM OTHER SUBMODELS

- streamflow (a · ft/month for April to August)
- depth to water table (ft)*
- sediment load (tons/year)*
- precipitation (in/month)
- mean maximum daily temperature/month
- % utilization (by vegetation type and spatial unit)
- # cattle use months/ spatial unit

TO OTHER SUBMODELS

- shade factor for fish
- % herbaceous, shrub and tree cover
- % protein content of hay
- hay produced (tons)
- forage for cattle (lbs/a; #a, % protein by vegetation type and growth rate)

---

*not included in preliminary model

Figure 3.1: Responsibilities of the vegetation/wildlife submodel.

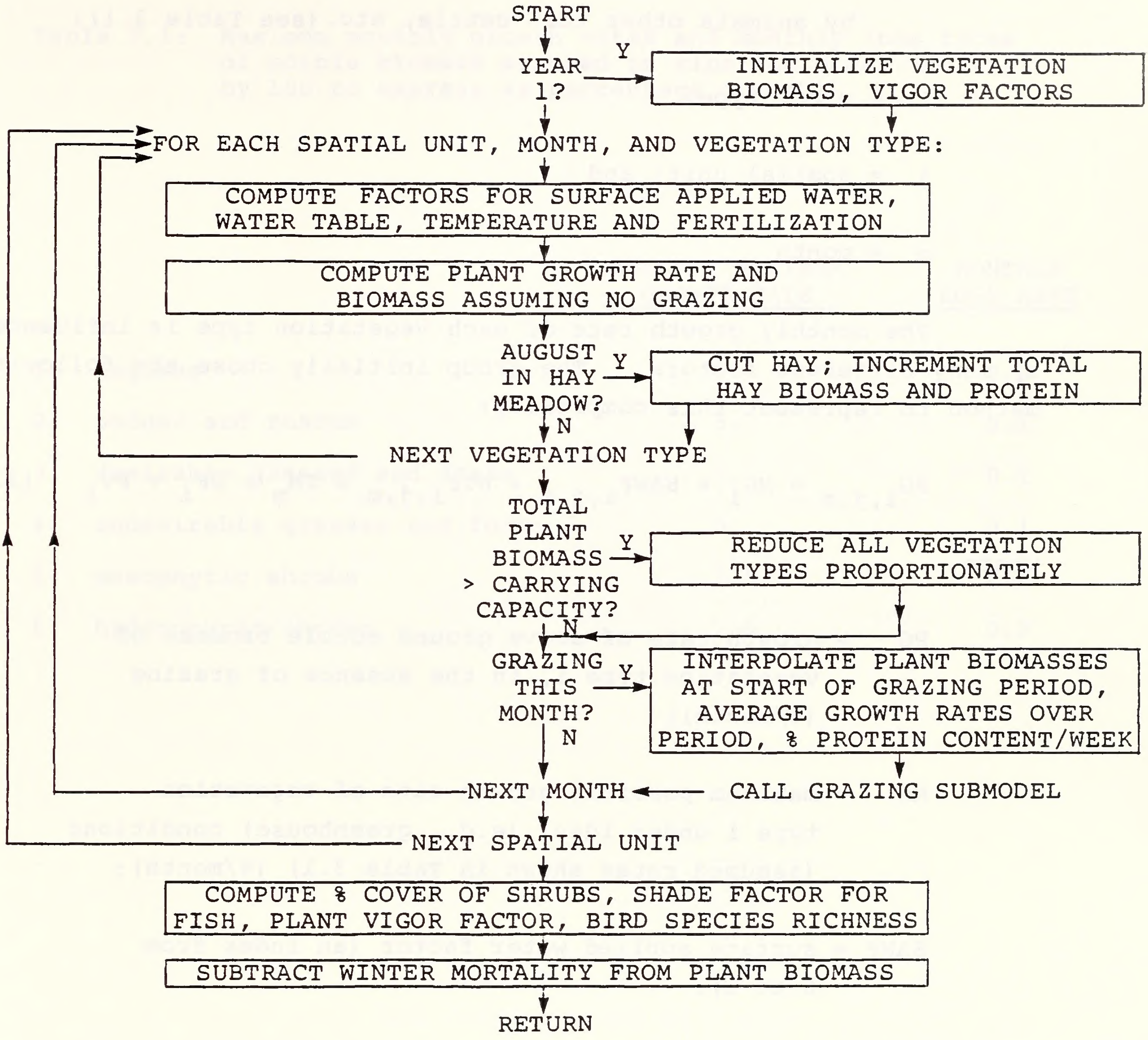

START
YEAR 1?
Y
INITIALIZE VEGETATION BIOMASS, VIGOR FACTORS
FOR EACH SPATIAL UNIT, MONTH, AND VEGETATION TYPE:
COMPUTE FACTORS FOR SURFACE APPLIED WATER, WATER TABLE, TEMPERATURE AND FERTILIZATION
COMPUTE PLANT GROWTH RATE AND BIOMASS ASSUMING NO GRAZING
AUGUST IN HAY MEADOW?
Y
CUT HAY; INCREMENT TOTAL HAY BIOMASS AND PROTEIN
N
NEXT VEGETATION TYPE
TOTAL PLANT BIOMASS > CARRYING CAPACITY?
Y
REDUCE ALL VEGETATION TYPES PROPORTIONATELY
N
GRAZING THIS MONTH?
Y
INTERPOLATE PLANT BIOMASSES AT START OF GRAZING PERIOD, AVERAGE GROWTH RATES OVER PERIOD, % PROTEIN CONTENT/WEEK
N
NEXT MONTH
CALL GRAZING SUBMODEL
NEXT SPATIAL UNIT
COMPUTE % COVER OF SHRUBS, SHADE FACTOR FOR FISH, PLANT VIGOR FACTOR, BIRD SPECIES RICHNESS
SUBTRACT WINTER MORTALITY FROM PLANT BIOMASS
RETURN

Figure 3.2: Sequence of calculations for the vegetation/wildlife submodel.

ML = loss rate of biomass due to senescence, grazing by animals other than cattle, etc. (see Table 3.1);

i = plant type;

j = spatial unit; and

m = month.

The monthly growth rate of each vegetation type is influenced by many different factors. The group initially chose the following method to represent this complexity:

$$PG_{i,j,m} = MG_{i} * SAWF_{i,j,m} * WTF_{i,j,m} * TM_{m} * PF_{i} * PV_{i} \qquad (3.2)$$

where,

PG = growth rate of above ground edible biomass of vegetation type i, in the absence of grazing (%/month);

MG = maximum possible growth rate of vegetation type i under ideal (e.g., greenhouse) conditions (assumed rates shown in Table 3.1) (%/month);

SAWF = surface applied water factor (an index from 0 to 1);

WTF = water table factor (0 - 1);

TM = temperature factor (0 - 1);

PF = fertilization factor (0 - 1); and

PV = plant vigor factor (0 - 1).

Table 3.1: Maximum monthly growth rates and monthly loss rates of edible biomass assumed in riparian model (multiply by 100 to express as percentage growth).

	MONTHLY MAXIMUM GROWTH RATE	MONTHLY LOSS RATE
1. legumes	3.	0.2
2. sedges and rushes	3.	0.1
3. desirable grasses and forbs	3.	0.1
4. undesirable grasses and forbs	3.	0.1
5. mesophytic shrubs	1.5	0.2
6. hydrophytic shrubs	1.5	0.2

Each of these factors is described below.

Since it was soon discovered that Equation (3.2) exaggerated the interdependency of the various factors, an alternate form was used:

$$PG_{i,j,m} = MG_i * \frac{(SAWF_{i,j,m} + WTF_{i,j,m} + TM_m + PF_i + PV_i)}{5} \quad (3.3)$$

3.2.1 Surface Applied Water Factor (SAWF)

The optimum amount of water for plant growth was considered to be related to the optimal rate of evapotranspiration exhibited by the plant, which varies both seasonally and with the type of vegetation (Table 3.2). SAWF was computed by the following equations:

$$SAWF_{i,m} = COS \left[\left(\frac{LI_m - ET_{i,m}}{RWT}\right) * \frac{\pi}{2}\right] \qquad \text{if } |LI_m - ET_{i,m}| \leq RWT \quad (3.4)$$

$$SAWF_{i,m} = 0 \qquad \text{if } |LI_m - ET_{i,m}| > RWT$$

where,

LI_m = amount of surface water applied in month m (precipitation plus irrigation) (ft);

$ET_{i,m}$ = optimum amount of evapotranspiration for plant type i in month m (ft); and

RWT = range of water tolerance above and below optimum (ft).

This equation is illustrated in Figure 3.3.

Table 3.2: Assumed optimal rates of evapotranspiration for each plant type and month.

MONTH	OPTIMAL RATE OF EVAPOTRANSPIRATION (ft/month)			
	LEGUMES	SEDGES/ RUSHES HYDROPHYTIC SHRUBS	DESIRABLE AND UNDESIRABLE GRASSES AND FORBS	MESOPHYTIC SHRUBS
April	0.05	0.07	0.04	0.02
May	0.25	0.33	0.2	0.1
June	0.5	0.67	0.4	0.2
July	0.5	0.67	0.4	0.2
August	0.4	0.53	0.32	0.08
September	0.3	0.4	0.24	0.12
October	0.15	0.2	0.12	0.06

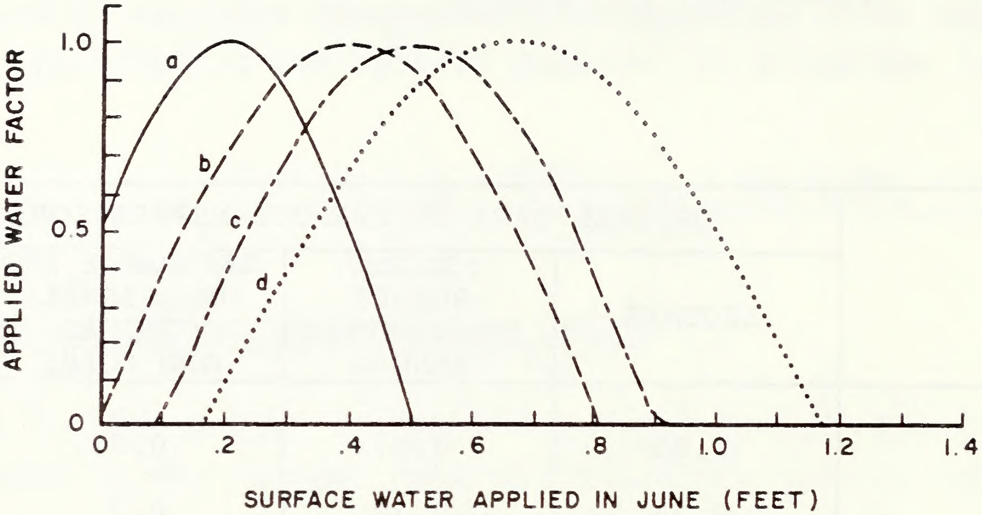


Figure 3.3: Surface Applied Water Factor for each vegetation type in June. Curves for other months obtained by scaling on optimum evapotranspiration (see Table 3.2).

a = mesophytic shrubs;

b = grasses and forbs;

c = legumes; and

d = sedges and rushes, hydrophytic shrubs.

3.2.2 Water Table Factor (WTF)

Separate curves were created for each vegetation type, based on the participants' assessment of relative water tolerances (Figure 3.4). These curves were assumed to be unaffected by season. The basic equation used to compute WTF is:

$$WTF_{i,m} = \cos\left[\left(\frac{WD_m - OD_i}{RD_i}\right) * \frac{\Pi}{2}\right] \qquad (3.5)$$

where,

WD_m = depth of water table in month m (ft);

OD_i = optimum depth of water table for vegetation type i (ft); and

RD_i = range of tolerable water table depths above and below optimum.

Different values of RD_i are used above and below the optimum in order to yield assymetric curves shown in Figure 3.4.

3.2.3 Temperature Factor (TM)

The temperature factor was assumed to follow Figure 3.5, the same relationship used in the integrated model (Sonntag et al., 1982).

3.2.4 Fertilization Factor (PF)

Application of nitrogen fertilizer favors types of vegetation which cannot fix atmospheric nitrogen (i.e., the five types other than legumes). The relationships illustrated in Figure 3.6 were used to simulate this phenomenon. Fertilization with phosphorus, which promotes legume production, was discussed but was considered to be unlikely.

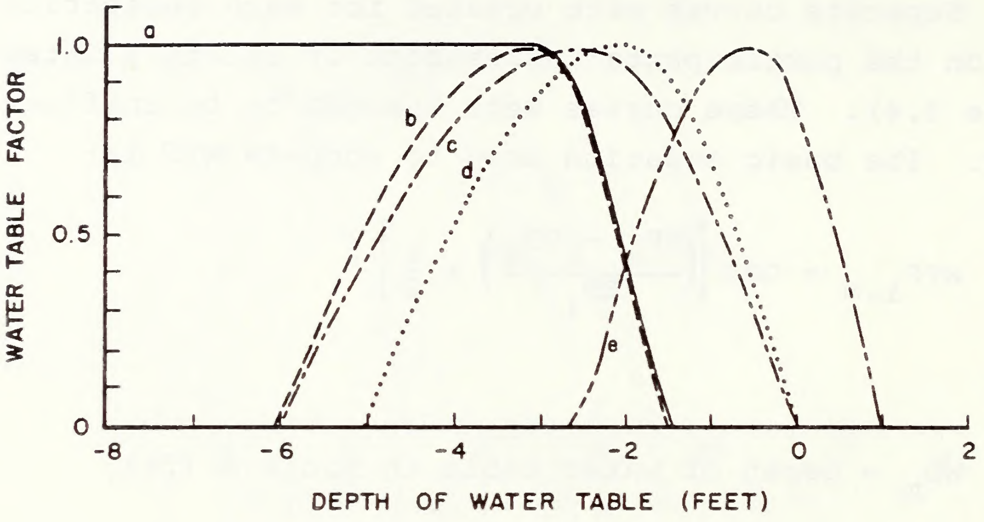


Figure 3.4: Water Table Factor as a function of water table depth. With irrigation, effects of low water table reduced or eliminated.

a = mesophytic shrubs;

b = hydrophytic shrubs;

c = grasses and forbs;

d = legumes; and

e = sedges and rushes.

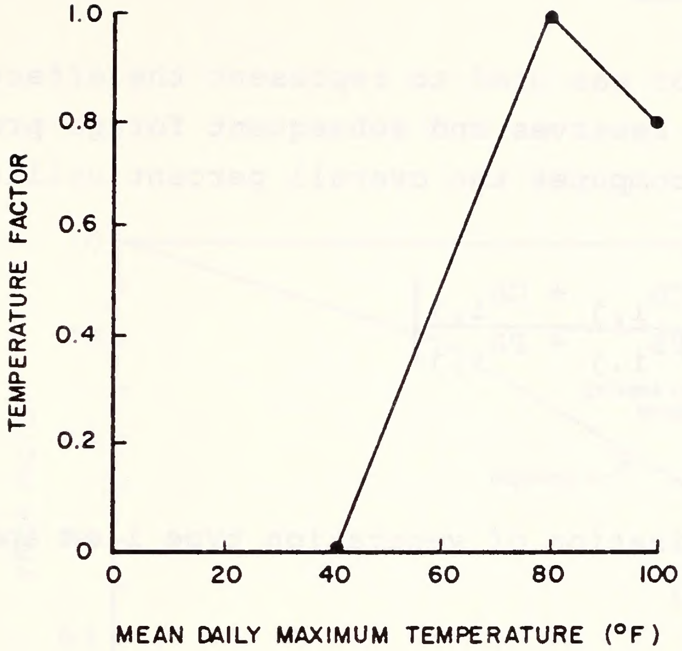


Figure 3.5: Temperature factor.

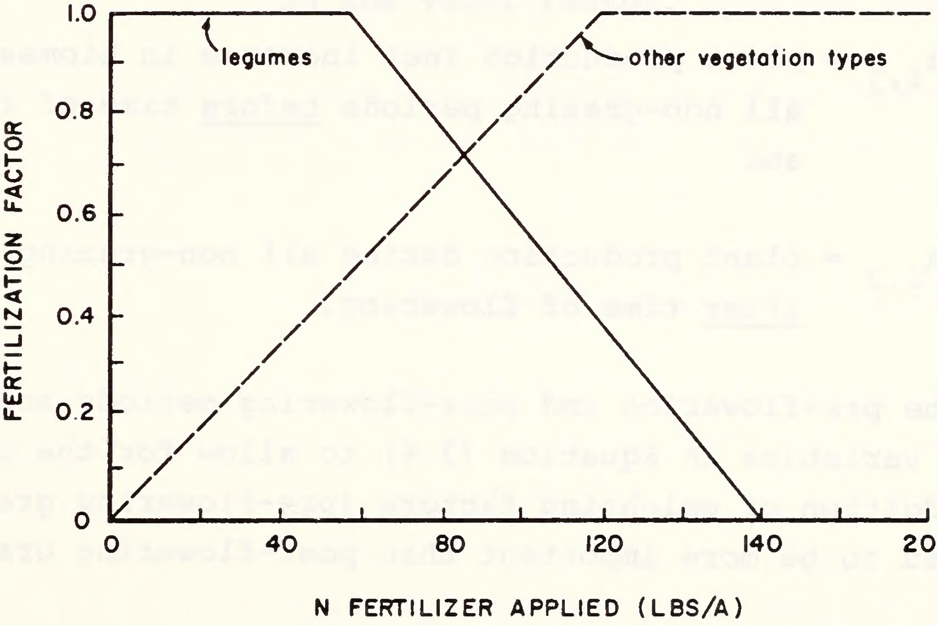


Figure 3.6: Effects of additions of nitrogen fertilizer on the fertilization factor.

3.2.5 Vigor Factor (PV)

The vigor factor was used to represent the effect of cattle grazing on plant root reserves and subsequent forage production. Each year, the model computes the overall percent utilization of each vegetation type:

$$UT_{i,j} = 100 * \left[\frac{CB_{i,j} + CA_{i,j}}{PB_{i,j} + PA_{i,j}}\right] \qquad (3.6)$$

where,

$UT_{i,j}$ = % utilization of vegetation type i on spatial unit j;

$CB_{i,j}$ = biomass of vegetation consumed by cattle before flowering of plant (assumed to be last week of July);

$CA_{i,j}$ = biomass of vegetation consumed by cattle after flowering;

$PB_{i,j}$ = plant production (net increase in biomass) during all non-grazing periods before time of flowering; and

$PA_{i,j}$ = plant production during all non-grazing periods after time of flowering.

The pre-flowering and post-flowering periods are given separate variables in Equation (3.6) to allow for the possible future addition of weighting factors (pre-flowering grazing was considered to be more important than post-flowering grazing).

Repeated overgrazing was considered harmful, whereas episodic heavy grazing was not. Therefore, the functional relationship used to compute the vigor factor (Figure 3.7) relies upon the three year average utilization.

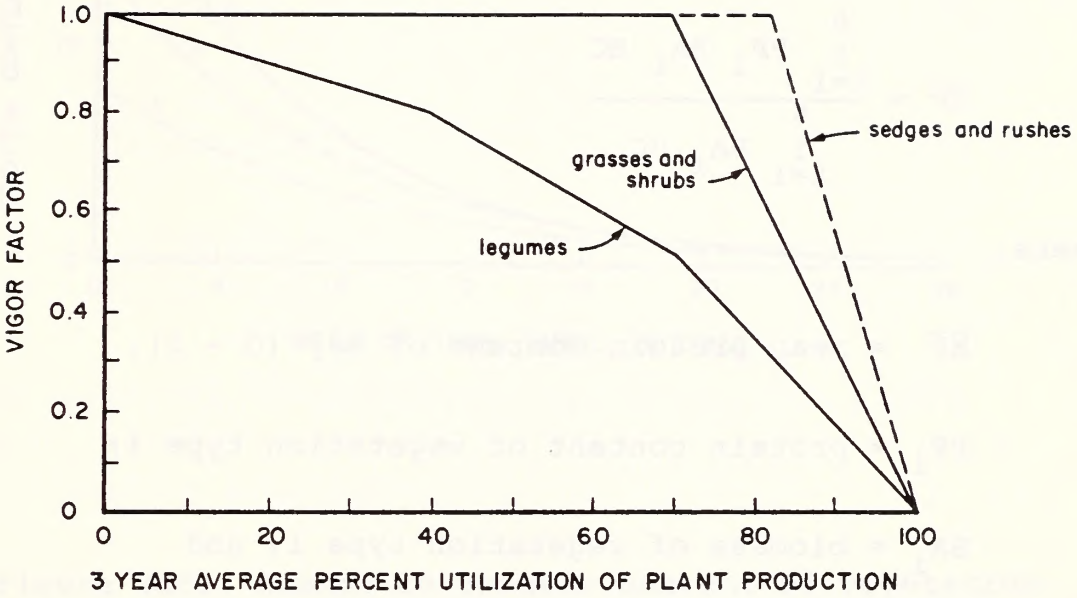


Figure 3.7: Effect of average percent utilization on the vigor factor.

3.3 Hay Production

At the start of August, 90% of all vegetation biomass on the hay meadow spatial unit is removed as hay. The mean protein content of the hay is computed as:

$$\overline{HP} = \frac{\sum_{i=1}^{6} PP_i \; BA_i \; HC}{\sum_{i=1}^{6} BA_i \; HC} \tag{3.7}$$

where,

$\overline{HP}$ = mean protein content of hay (0 - 1);

PP_i = protein content of vegetation type i;

BA_i = biomass of vegetation type i; and

HC = proportion of hay meadow vegetation that is cut.

3.4 Protein Content

Data provided at the workshop was used to fit the curves shown in Figure 3.8. Note that protein content depends only on the time of year.

3.5 Percent Cover and Bank Shading Factor

The subgroup was not able to find satisfactory functional relationships for predicting percent cover, but accepted the following equations as a first guess:

$$PS_j = \frac{(BA_{5,j} + BA_{6,j}) * 100}{2000 + (BA_{5,j} + BA_{6,j})} \tag{3.8}$$

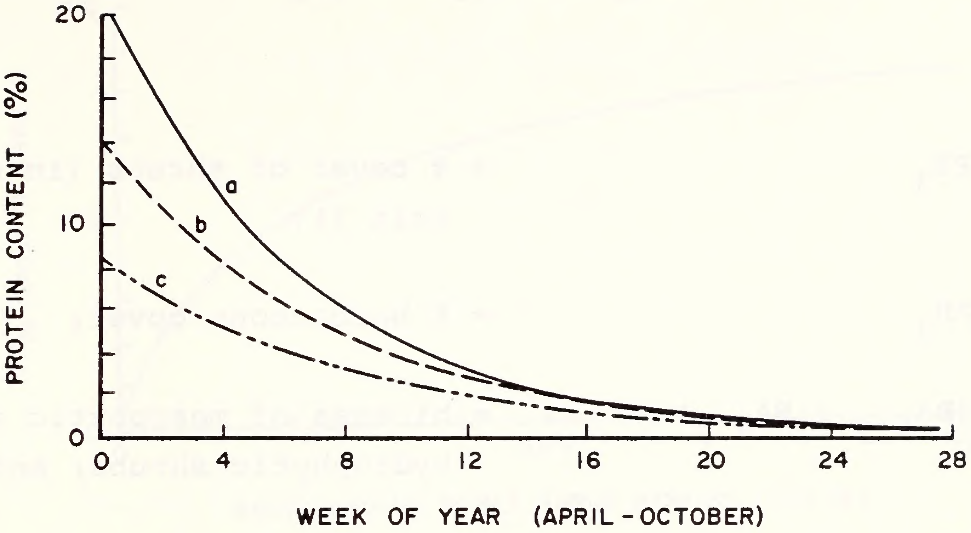


Figure 3.8: Change in protein content of vegetation over time.

a = legumes;

b = sedges and rushes, all grasses and forbs; and

c = all shrubs.

$$PH_j = \frac{(BA_{1,j} + BA_{3,j} + BA_{4,j}) * 100}{500 + (BA_{1,j} + BA_{3,j} + BA_{4,j})} \qquad (3.9)$$

where,

PS_j = % cover of shrubs (in spatial unit j);

PH_j = % herbaceous cover;

$(BA_{5,j} + BA_{6,j})$ = biomass of mesophytic and hydrophytic shrubs; and

$(BA_{1,j} + BA_{3,j} + BA_{4,j})$ = biomass of legumes, desirable grasses and forbs, and undesirable grasses and forbs.

These equations are shown in Figure 3.9.

The percent bank shading was set equal to the percent cover of shrubs and trees, the latter being fixed for each spatial unit.

3.6 Non-Game Bird Species Richness

The potential number of bird species nesting in shrubs was predicted from the percent shrub cover, according to the functional relationship shown in Figure 3.10.

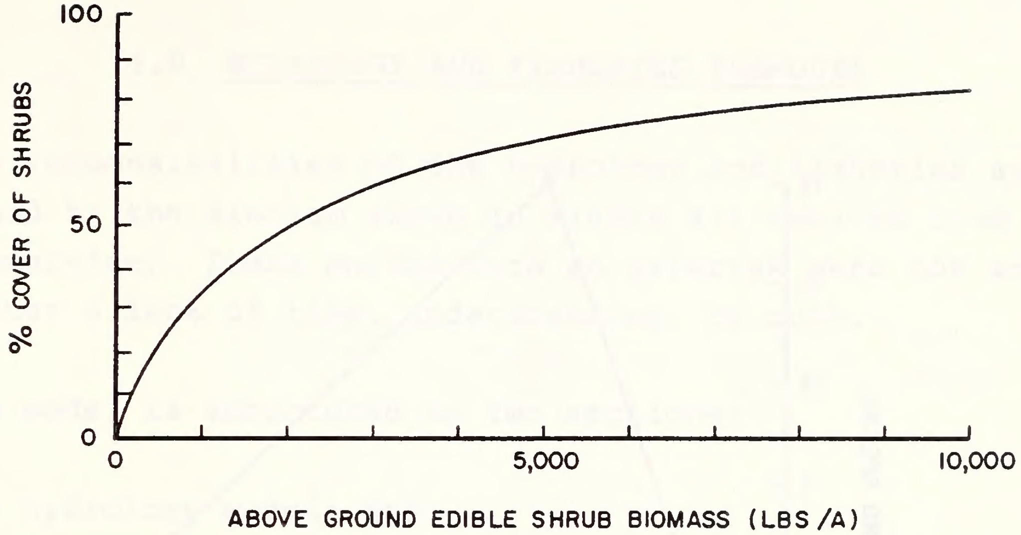


Figure 3.9a: Percent cover of shrubs.

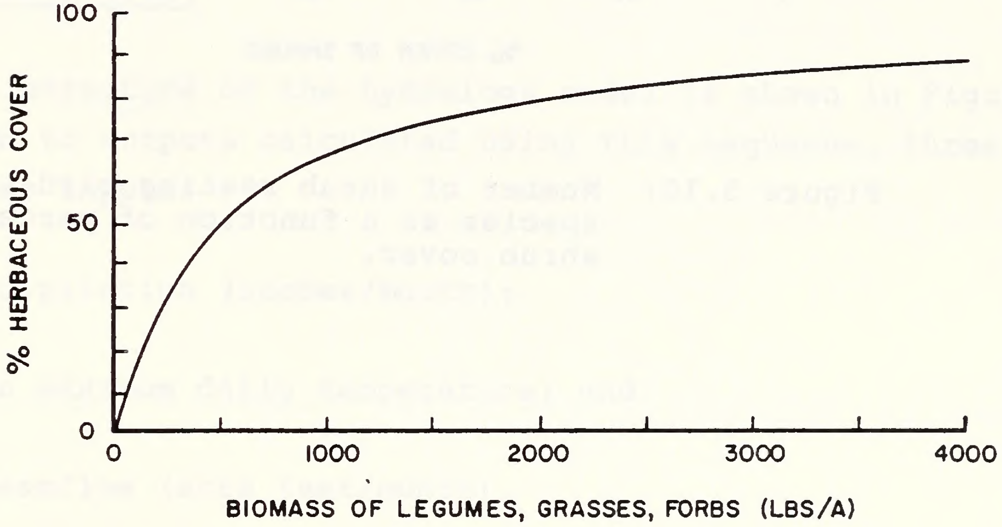


Figure 3.9b: Percent herbaceous cover.

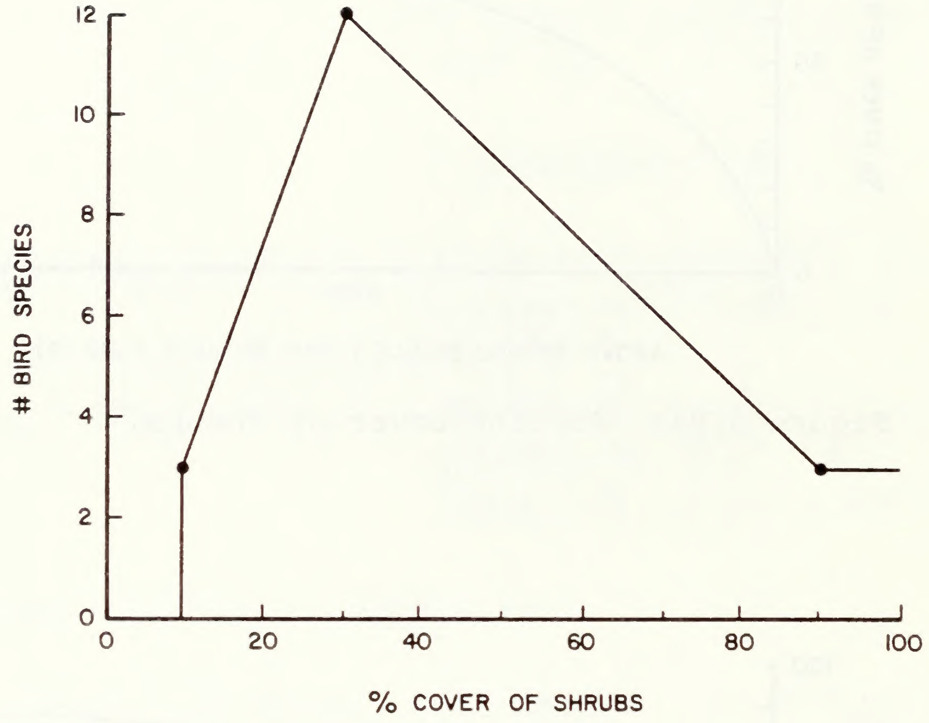


Figure 3.10: Number of shrub resting bird species as a function of percent shrub cover.

4.0 HYDROLOGY AND FISHERIES SUBMODEL

The responsibilities of the hydrology and fisheries subgroup were defined by the diagram shown in Figure 4.1 derived from the bounding exercise. Items marked with an asterisk were not addressed due to either a lack of time, understanding, or both.

The model is structured in two sections:

1) the hydrology model; and

2) the fisheries model.

These will be discussed in the following two sections.

4.1 Hydrology Model

The structure of the hydrology model is shown in Figure 4.2a. In addition to outputs calculated using this sequence, three others are taken as inputs:

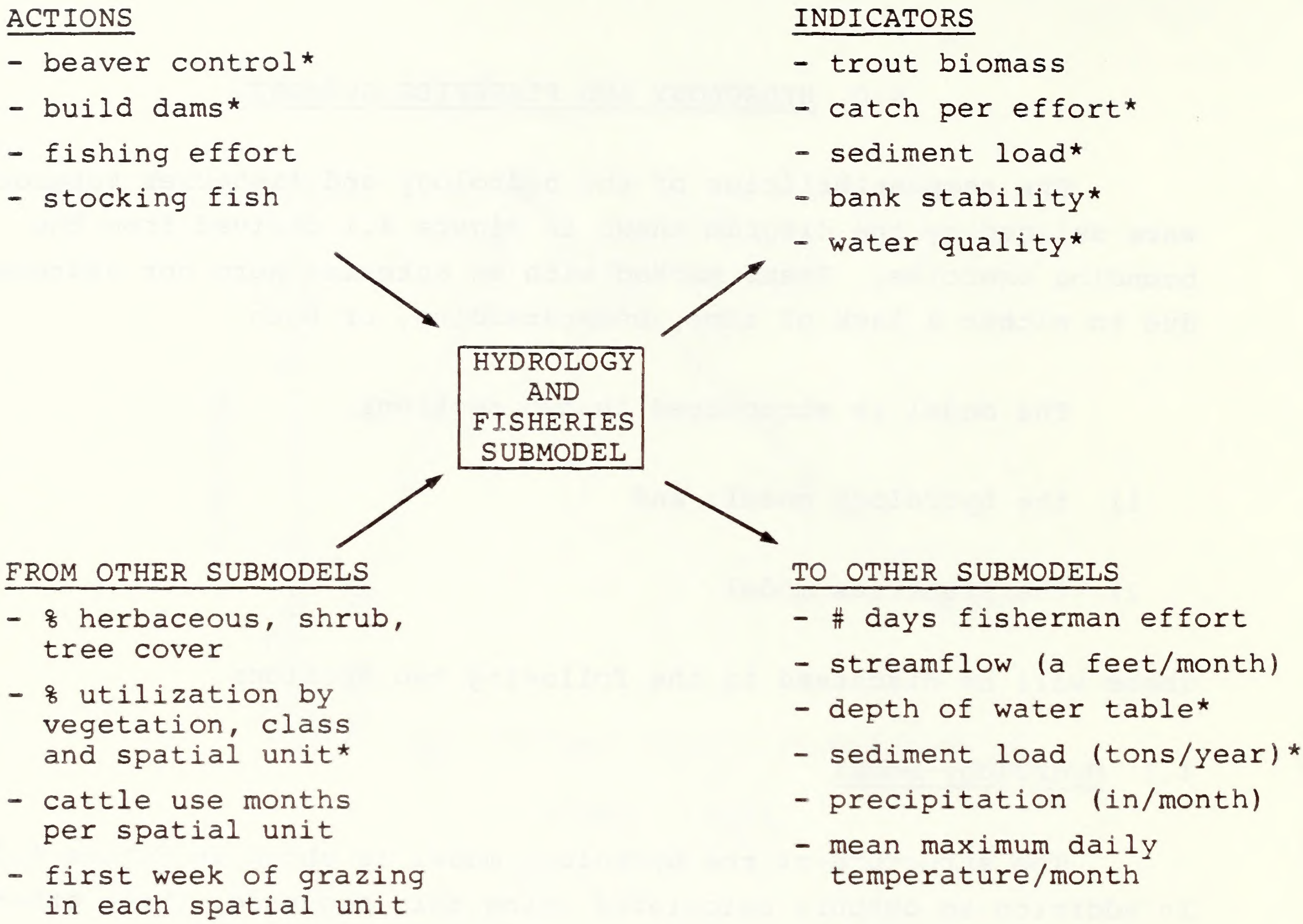
1) precipitation (inches/month);

2) mean maximum daily temperature; and

3) streamflow (acre feet/month).

Thus, the monthly patterns of these outputs do not change from year to year.

The main part of the hydrology model is concerned with changes in stream channel morphology in response to cattle-induced erosion. For the purposes of the model, the channel is assumed to have a rectangular cross section as shown in Figure 4.3.



ACTIONS

- beaver control*
- build dams*
- fishing effort
- stocking fish

INDICATORS

- trout biomass
- catch per effort*
- sediment load*
- bank stability*
- water quality*

FROM OTHER SUBMODELS

- % herbaceous, shrub, tree cover
- % utilization by vegetation, class and spatial unit*
- cattle use months per spatial unit
- first week of grazing in each spatial unit

TO OTHER SUBMODELS

- # days fisherman effort
- streamflow (a feet/month)
- depth of water table*
- sediment load (tons/year)*
- precipitation (in/month)
- mean maximum daily temperature/month

Figure 4.1: Responsibilities of the hydrology/fisheries submodel.

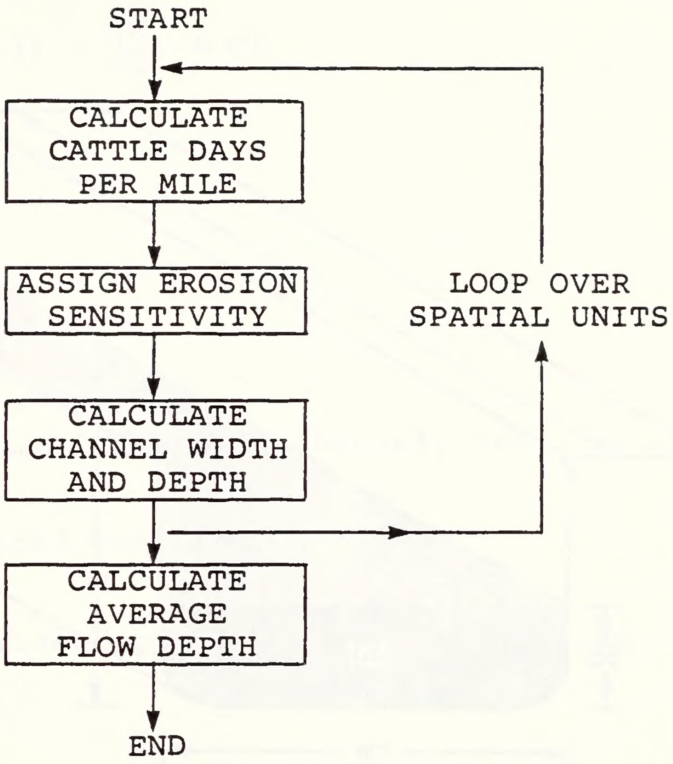

START
CALCULATE CATTLE DAYS PER MILE
ASSIGN EROSION SENSITIVITY
CALCULATE CHANNEL WIDTH AND DEPTH
CALCULATE AVERAGE FLOW DEPTH
END
LOOP OVER SPATIAL UNITS

Figure 4.2a: Flow chart showing structure of hydrology submodel.

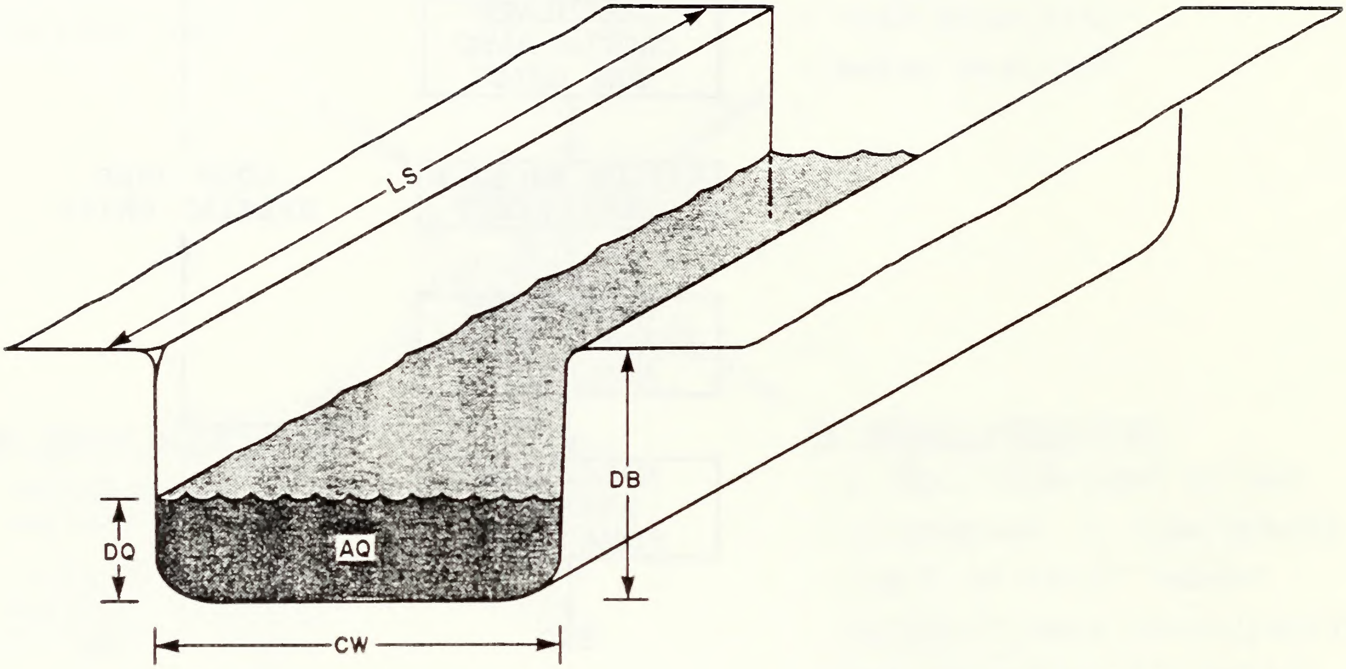


Figure 4.3: Diagram showing the representation of a stream reach used in the model.

AQ = cross sectional area in feet^3;

CW = channel width in feet;

DB = bank full depth in feet;

HB = CW * DB;

DQ = flow depth in inches;

LS = stream reach length in miles.

The basic rule for changing the geometry of the stream channel is:

$$CW = CW + CW * MR * (1 - \frac{CW}{CE}) + CZ \qquad (4.1)$$

where,

CW = channel width;

MR = a rate constant;

CE = the equilibrium width of the channel; and

CZ = the cattle-induced widening.

The cattle-induced widening is calculated using the relationship:

$$CZ = \frac{1}{DB} * BS * \frac{1}{DENSITY} * (1 - 0.009 * SF) * CM * EC \qquad (4.2)$$

where,

DB = the bankful depth of the channel;

DENSITY = mean density of soil;

SF = bank shading factor (%);

CM = cattle days per mile;

EC = erosion due to cattle in tons/cattle day; and

BS = bank stability depending on time of year.

The number of cattle days per mile is calculated from the cattle use months per spatial unit according to the relationship:

$$CM = \frac{CD}{AZ} * \frac{AB}{AZ} * AC * BC \qquad (4.3)$$

where,

AC, BC = conversion factors;

CD = cattle months per spatial unit;

AB = area in acres of bank; and

AZ = total area in acres of spatial unit.

This simply assumes the cattle spread randomly throughout each spatial unit.

The bank stability factor is obtained from Table 4.1 and depends only on the week.

Once the channel morphology has been calculated, the water depth is estimated by assuming a mean velocity of 2 feet/second and by using the mean monthly flow:

$$AQ = \frac{QM}{CC} \qquad (4.4)$$

where,

AQ = cross sectional area;

QM = mean flow; and

CC = assumed mean velocity. It then follows that:

$$DQ = \frac{AQ}{CW} \qquad (4.5)$$

Table 4.1: Bank stability factor.

WEEK IN YEAR*	STABILITY FACTOR
1 - 8	1
9 - 20	0.5
21 - 51	0.3
52	0

where,

DQ = flow depth.

The mean flow depth is averaged over the three stream reaches (DA) for use in the fisheries submodel.

4.2 Fisheries Model

The structure of the fisheries model is shown in Figure 4.2b. Each of the components will be described below.

4.2.1 Recruitment

The number of eggs is estimated by assuming that each female in the third age class produces 800 eggs for each pound of body weight. The total number of viable eggs produced by the population is constrained to be less than 50,000 to simulate a certain amount of density dependence.

Once layed, eggs are subjected to three types of mortality: a vegetative factor (Figure 4.4a), a flow depth factor (Figure 4.4b), and finally a base factor intended to cover all other types of mortality.

4.2.2 Growth

Newly hatched fry are assumed to weigh 10 grams and then grow according to the same rules as all other fish:

$$\text{Gain in weight} = 4 * AV * GP \qquad (4.6)$$

where,

AV = vegetative factor from Figure 4.4a; and

GP = growth multiplier from Figure 4.4c.

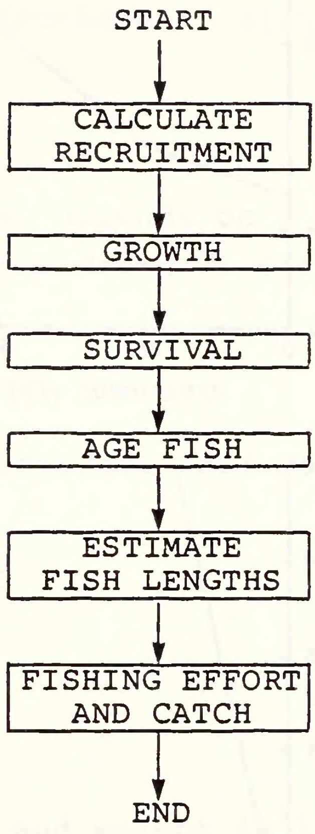


Figure 4.2b: Flow chart showing the structure of the fisheries model.

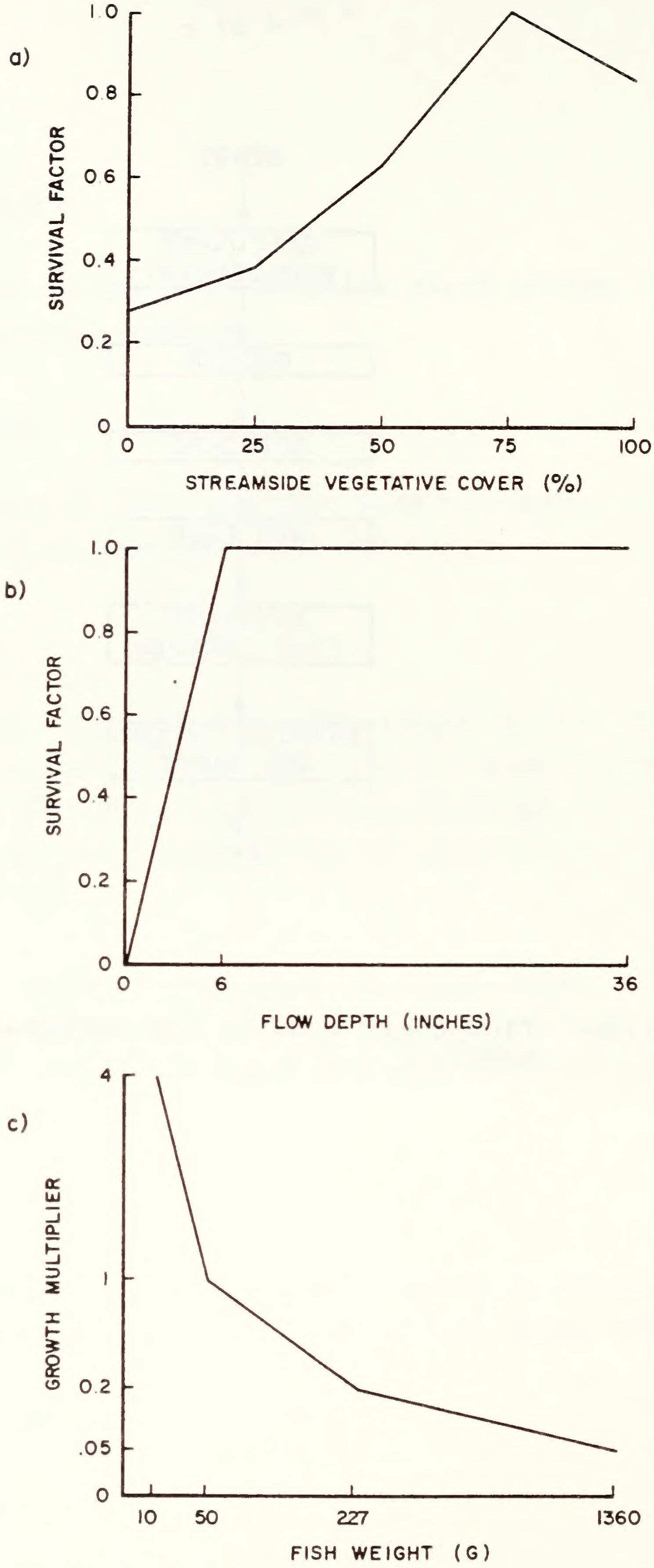


Figure 4.4: Relationships used in the fisheries submodel.

The growth multiplier reflects the fish putting less and less energy into growth as they increase in size.

4.2.3 Survival

Survival for all fish depends on a base rate, multiplied by the vegetative factor and the depth factor.

4.2.4 Fish Lengths

Fish lengths are calculated from weights using the relationship:

$$\text{LENGTH} = \left(\frac{\text{WEIGHT}}{3}\right)^{0.5}$$

where,

LENGTH is in inches and weight is in grams.

4.2.5 Fishing

Angler effort measured in fisherman days per mile is estimated from the number of fish greater than 6 inches using the relationship shown in Figure 4.5. The number of fish caught is estimated using the relationship:

$$CT = CV * CR * 3$$

where,

CT = # of fish caught/mile;

CV = angler effort in days;

CR = (# fish > 6")/500/per mile; and

3 = catchability coefficient.

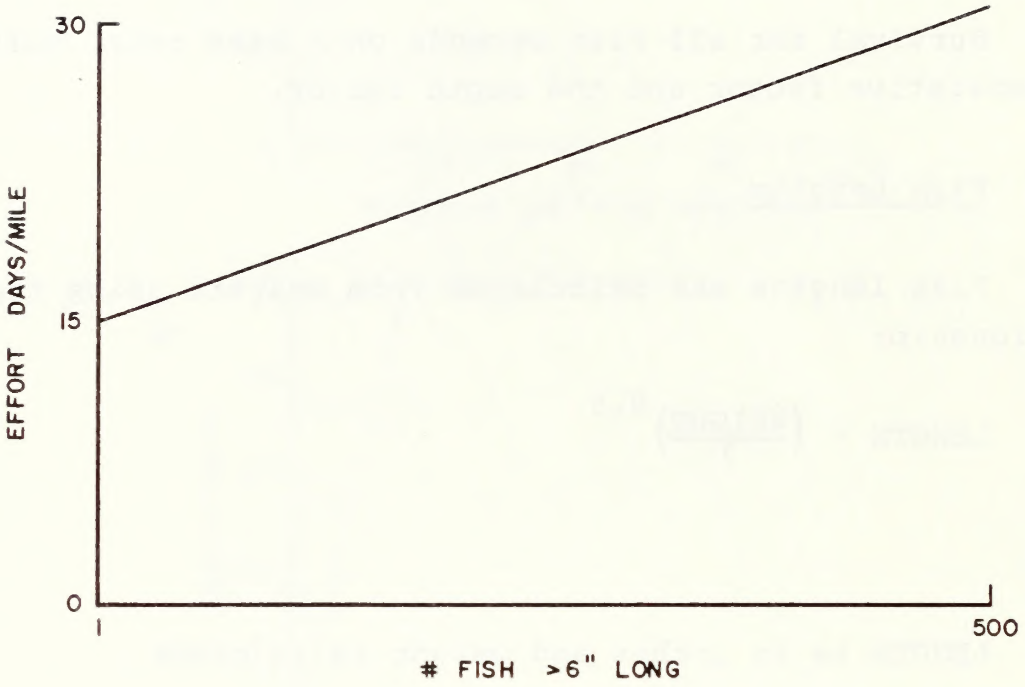


Figure 4.5: Relationship between number of fish greater than 6" long and angler effort.

It is assumed that fish are taken equally from all age classes in proportion to the number greater than 6 inches long.

5.0 CATTLE/ECONOMICS SUBMODEL

5.1 Model Structure

The cattle/economics submodel consists of four major sections (Figure 5.1):

1) the dynamics of livestock grazing in the mountain and alluvial spatial units in response to rotation schemes, cattle herd sizes, forage levels, and vegetation protein content;

2) weekly vegetation dynamics;

3) determination of fall weights of cattle and economic revenues from animals which are sold; and

4) cattle use of the mountain and alluvial spatial units.

The order in which the cattle/economics submodel considers these processes is presented in Figure 5.2.

Interactions between forage and cattle occur only in those time periods in which the rotation scheme allows cattle to be on either the mountain or alluvial spatial units. During these periods of interaction, the cattle/economics model simulates cattle use, grazing and vegetation growth processes on a weekly time step. Forage biomasses and consumption rates are passed back to the vegetation model for each month of the grazing period. The dynamics of cattle growth during the time periods they use the mountain and alluvial spatial units are then used as surrogates of cattle growth for the entire spring and summer to calculate economic revenues.

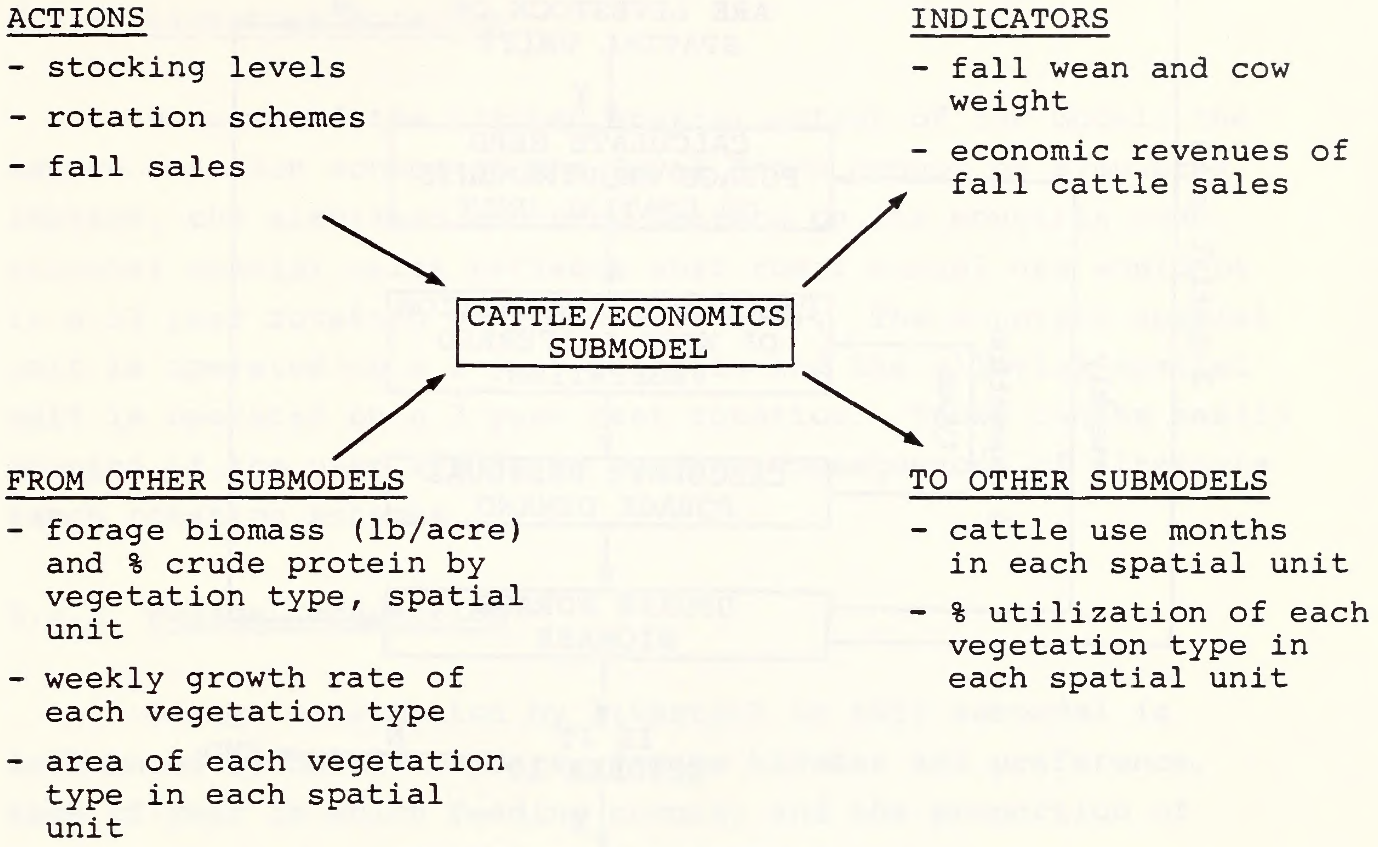

ACTIONS
- stocking levels
- rotation schemes
- fall sales
INDICATORS
- fall wean and cow weight
- economic revenues of fall cattle sales
CATTLE/ECONOMICS SUBMODEL
FROM OTHER SUBMODELS
- forage biomass (lb/acre) and % crude protein by vegetation type, spatial unit
- weekly growth rate of each vegetation type
- area of each vegetation type in each spatial unit
TO OTHER SUBMODELS
- cattle use months in each spatial unit
- % utilization of each vegetation type in each spatial unit

Figure 5.1: Responsibilities of the cattle/economics submodel.

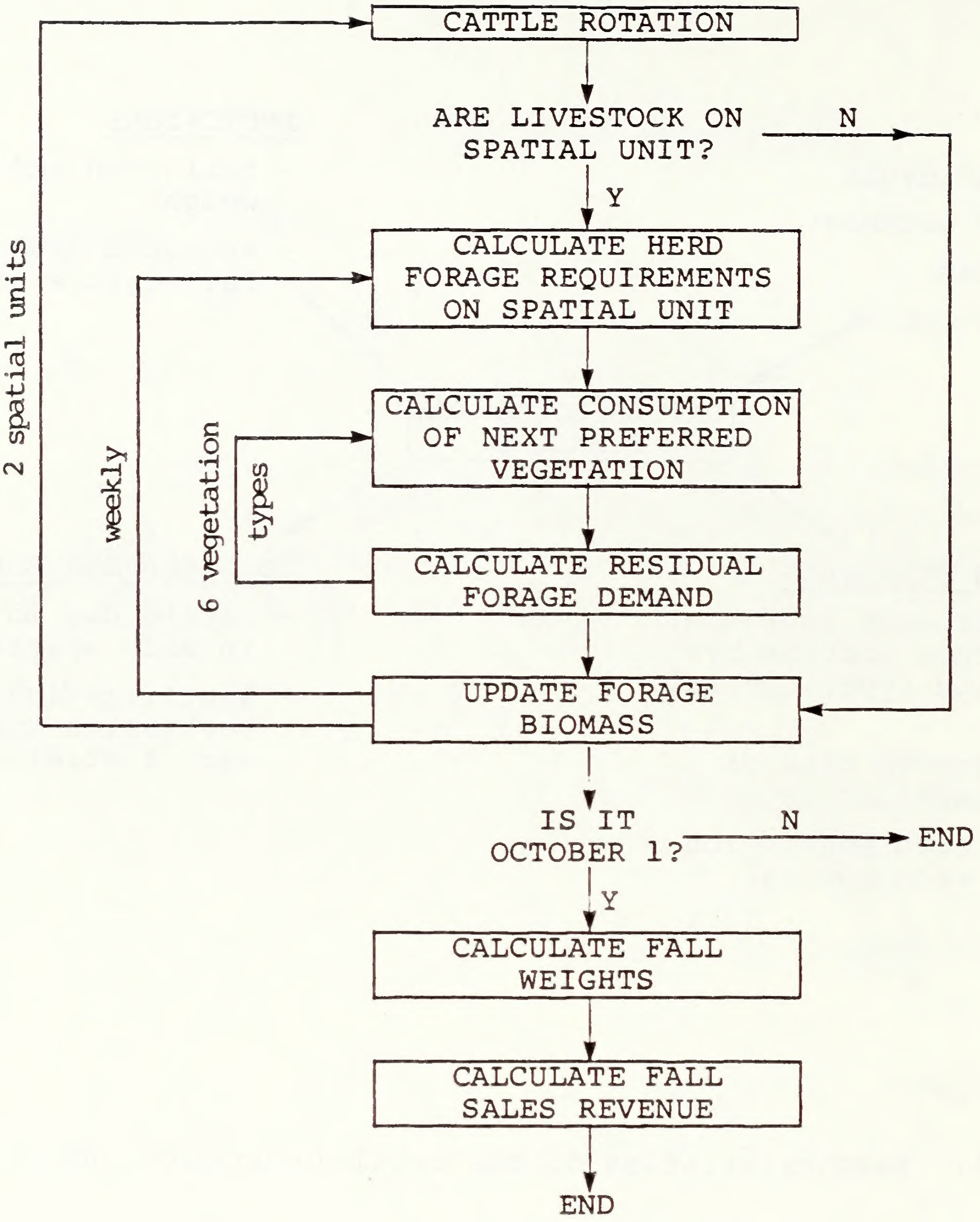

CATTLE ROTATION
ARE LIVESTOCK ON SPATIAL UNIT?
N
Y
CALCULATE HERD FORAGE REQUIREMENTS ON SPATIAL UNIT
CALCULATE CONSUMPTION OF NEXT PREFERRED VEGETATION
CALCULATE RESIDUAL FORAGE DEMAND
UPDATE FORAGE BIOMASS
2 spatial units
weekly
6 vegetation types
IS IT OCTOBER 1?
N
END
Y
CALCULATE FALL WEIGHTS
CALCULATE FALL SALES REVENUE
END

Figure 5.2: Sequence of calculations for the cattle/economics submodel.

5.2 Livestock Grazing

5.2.1 Livestock Rotation

Because of the limited spatial extent of the model, the entire rotation scheme of the Saval Ranch cannot be simulated. Instead, the simulated stocking pattern on the mountain and alluvial spatial units reflects what their annual use would be in a 12 year rotation period (Table 5.1). The mountain spatial unit is operated on a 2 year rotation and the alluvial spatial unit is operated on a 3 year rest rotation. These can be easily changed if the user wishes to examine consequences of alternate ranch rotation schemes.

5.2.2 Forage Consumption

Forage consumption by livestock in this submodel is influenced by cattle numbers, forage biomass and preference, time of year in which feeding occurs, and the proportion of feeding which occurs in the model spatial units.

The weekly forage demand in a given spatial unit is given by:

$$PR = YC * UC * SL_{i,t} * 200 \qquad (5.1)$$

where,

PR is the forage demand (lbs/week);

YC is the total number of cattle;

UC is the number of cattle equivalents per head (to reflect the fact that the herd contains animals of varying size and therefore forage requirements);

Table 5.1: Pattern of use of mountain and alluvial spatial units. This pattern is repeated every 6 years.

YEAR	SPATIAL UNIT*	DATE IN	DATE OUT	# WEEKS
1	MT	July 1/	August 15/	6/
	AL	June 1	June 15	3
2	MT	August 16/	September 30/	6/
		June 16	June 30	3
3	MT	July 1/	August 15/	6/
	AL	Rest	Rest	Rest
4	MT	August 16/	September 30/	6/
	AL	June 1	June 15	3
5	MT	July 1/	August 15/	6/
	AL	June 16	June 30	3
6	MT	August 16/	September 30/	6/
	AL	Rest	Rest	Rest

---

*MT = mountain; AL = alluvial

$SL_{i,t}$ is the proportion of grazing which occurs in spatial unit i in week t; and

200 is the pounds of forage demand for 1 livestock equivalent (25% of an AUM).

The number of cattle equivalents per head of cattle is set at 0.315 until August 1 and are then increased to 0.415 for the rest of the year. Changes in the proportion of time cattle grazing occurs in the areas considered by the model are given in Figure 5.3. Grazing in the mountain spatial unit is more episodic than in the alluvial, reflecting the differences in seasonal dynamics of vegetation growth in the two spatial units.

The distribution of grazing on each forage type is determined from the forage demand calculated from Equation (5.1) and by forage preference and availability. Forage preference is assumed to change throughout the year in the manner shown in Figure 5.4. The size of the bands at any point in time reflects the preference of that forage type; note that mesophytic shrubs are not consumed.

The preference values dictate the order in which forage will be consumed; the forage with the highest preference value is consumed first, followed by that with the second highest preference value, and so on, down to the forage with the lowest preference value. Consumption of a forage type* ($RP_{i,j}$) is calculated as the minimum of:

$$PR * PF_{j,t} * XE_{j-1} \tag{5.2}$$

and $$0.95 * BA_{i,j,t} * TA_i \tag{5.3}$$

where,

---

*The term "forage type" is equivalent to "vegetation type" (used in the vegetation/wildlife submodel description).

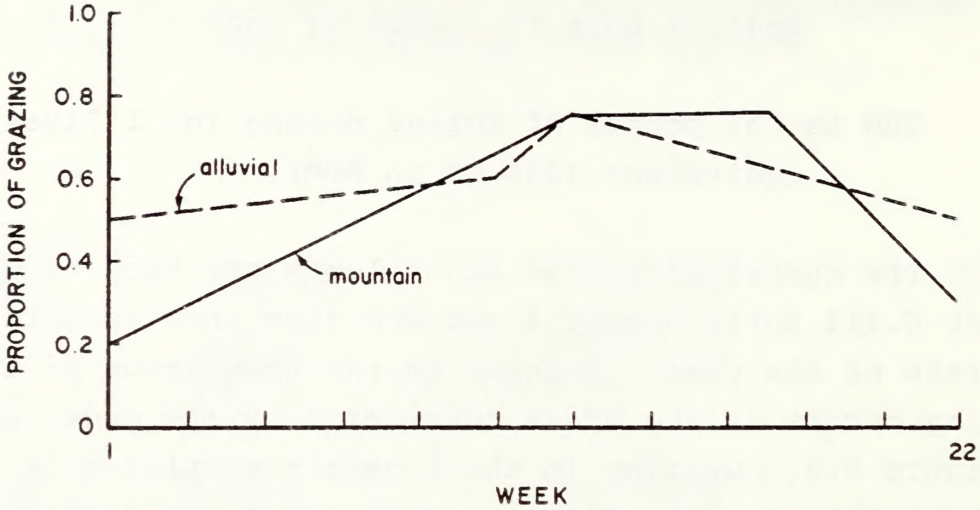


Figure 5.3: Proportion of grazing which occurs throughout the year in each spatial unit. This is used as a multiplier on total herd demand if cattle are in these spatial units.

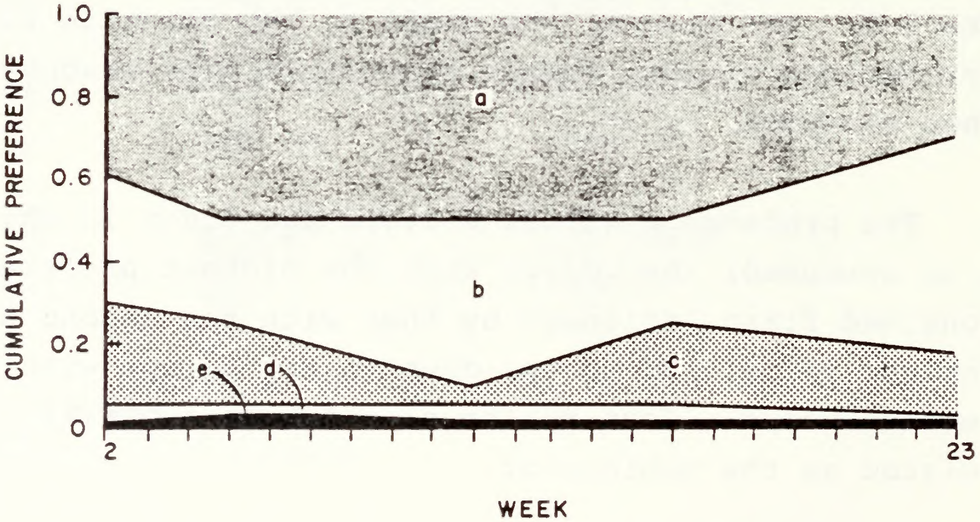


Figure 5.4: Preference for each vegetative type. The graph is of cumulative preference, so actual preference is designated as the width of each band.
a = legumes;
b = sedges and rushes;
c = desirable grasses and forbs;
d = undesirable grasses and forbs;
e = hydrophytic shrubs.
Mesophytic shrubs are not consumed.

$PF_{j,t}$ is the preference value for forage type j in week t (from Figure 5.4);

XE_{j-1} is the forage demand that was not met on previous forage types (explained below);

$BA_{i,j,t}$ is the pounds per acre of forage type j in spatial unit i; and

TA_i is the total area of spatial unit i.

Cattle are constrained to consuming a maximum of 95% of the forage in any forage class (Equation (5.3)).

Residual forage demand occurs if there is insufficient forage in a forage type to meet cattle demands for that forage type as defined by Equation (5.2). It is assumed that cattle will attempt to make up residual forage demand on less preferred forage types. Residual forage demand on the next most preferred forage type (type j) is calculated by:

$$XE_j = PR * PF_{j,t} * XE_{j-1} - RP_{i,j} \tag{5.4}$$

5.2.3 Total Forage Consumption and Consumption of Total Digestible Nutrients

Total forage consumption in a week is simply the sum of the consumption of individual forage types:

$$TS = \sum_{j=1}^{6} RP_{i,j} \tag{5.5}$$

Cattle weight gain is a function of total digestible nutrients (TDN) consumed by cattle. The amount of TDN in plant material is related to its crude protein content (Figure 5.5), so that the TDN consumed by cattle in a week (TD) is calculated by:

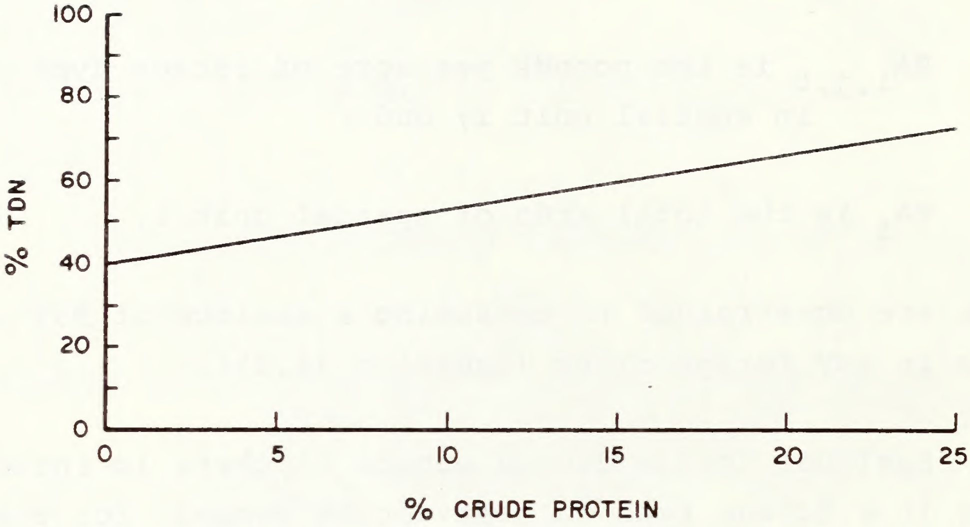


Figure 5.5: Relationship between percent crude protein and percent total digestible nutrients in forage.

$$TD = \sum_{j=1}^{6} RP_{i,j} * PD_j \qquad (5.6)$$

where,

PD_j is the proportion of forage biomass which is TDN.

Both TD and TS are accumulated for the time that cattle are in either spatial unit.

5.3 Vegetation Dynamics Within Livestock Model

The vegetation submodel contains detailed considerations of vegetation dynamics on a monthly time step. Because cattle can potentially use either spatial unit for a shorter period of time, and because cattle/forage interactions are tightly coupled, it is necessary to have some weekly dynamics of vegetation within the cattle/economics submodel.

The vegetation submodel provides an estimate of the weekly growth rate of each forage type each month. This and the forage consumption values are used to update forage biomass at the start of each week:

$$BA_{i,j,t+1} = (BA_{i,j,t} - RP_{i,j}) * (1 + RG_j) \qquad (5.6)$$

where,

RG_j is the net weekly growth rate for forage type j.*

5.4 Fall Cattle Weights and Economic Revenues

The model considers livestock grazing on the mountain and alluvial spatial units for a maximum of 7 weeks per year (Table 5.1). Fall cattle weights, however, are a function of cattle grazing throughout the spring, summer, and early fall. It was assumed that growth of cattle during the time they are on either of the two spatial units of concern is a good indicator of cattle growth dynamics over the entire grazing season. Therefore, fall weights are related to the amount of TDN consumed during the time cattle are on either of the two spatial units.

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*$RG = PG - ML$ (see Equation (3.1)).

A diet of forage with 55% TDN is assumed to give average fall weights for calves and cows. Therefore, the actual fall weights (WA) are calculated by:

$$WA = WN * \left[\frac{\sum_{i=1}^{n} (TD_i / TS_i)}{0.55} \right] \qquad (5.7)$$

where,

WN is the average fall weight (350 pounds for weaned calves and 900 pounds for cows);

TD_i and TS_i are the pounds of TDN and forage respectively consumed in week i; and

n is the number of weeks spent on the spatial unit.

Note that this equation would predict an average fall weight for a cow which ate only one pound of forage, provided that the pound had 55% TDN. Further checks need to be added to the model.

Weaned calves are sold in the fall; the revenues from these sales are calculated by:

$$SS = WA * (0.6 * YC) * 0.76 \qquad (5.8)$$

where,

SS = sales of weaned calves (\$); and

YC = number of cattle.

The model assumes that 60% of the herd in the fall is composed of weaned calves (both steer and heifer) and that calves sell for $.76/pound.

5.5 Cattle Use of Riparian Zones

The number of cattle months spent in each spatial unit (CD_i) depends upon the number of cattle, the duration of stay in each spatial unit, and the time of year.

$$CD_i = YC * \left(\frac{YD_i}{30}\right) * CU_t \tag{5.9}$$

where,

YD_i is the duration of stay in spatial unit in days (see Table 5.1); and

CU_t is a use factor which varies seasonally to reflect the birth and growth of calves in the spring and summer (Figure 5.6).

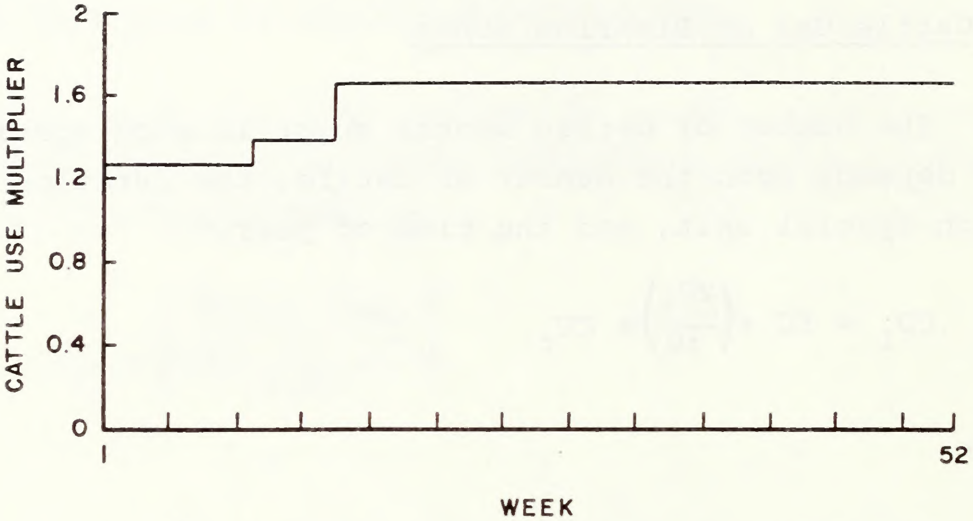


Figure 5.6: Annual change in cattle use multipliers used to calculate cattle use months.

6.0 REVIEW OF RIPARIAN ZONE RESEARCH ACTIVITIES

By creating an explicit conceptual model of the riparian system, the first workshop formed a firm perspective from which to examine ongoing research. First, a preliminary set of "impact hypotheses" was constructed based on the conceptual model developed at the first workshop. Each impact hypothesis connects one or more management actions with one or more indicators, via a series of linked ecological interactions. Some hypotheses are straightforward and involve only a few links, while others encompass greater complexity. The critical feature of all hypotheses is that they point towards what is required to demonstrate that management actions cause significant changes in system indicators.

The preliminary set of hypotheses formed the basic structure for a second workshop on the riparian zone, held March 27 to 29, 1984 at the University of Nevada (Reno).

During the workshop, the participants divided into subgroups to separately consider each impact hypothesis. Each subgroup consisted of five to ten scientists, plus one workshop facilitator. After clarifying the impact hypothesis (and correcting any parts which were unrealistic or ill-specified), each subgroup proceeded to discuss the evidence available to either support or refute the stated links. Where opportunities became apparent for applying existing data to address these links, the subgroup discussed what types of analyses should be performed. Next, the participants converged to one of five conclusions regarding the overall hypothesis and its component parts:

a) the hypothesis is not worth testing (because it is either obviously true or extremely unlikely);

b) the hypothesis is possible, but too hard to detect;

c) the hypothesis is testable within the Saval project if other research studies were undertaken concurrently with existing work;

d) the hypothesis is testable within the Saval project if existing research/monitoring designs were revised; or

e) the hypothesis is testable within the Saval project using existing research designs and data.

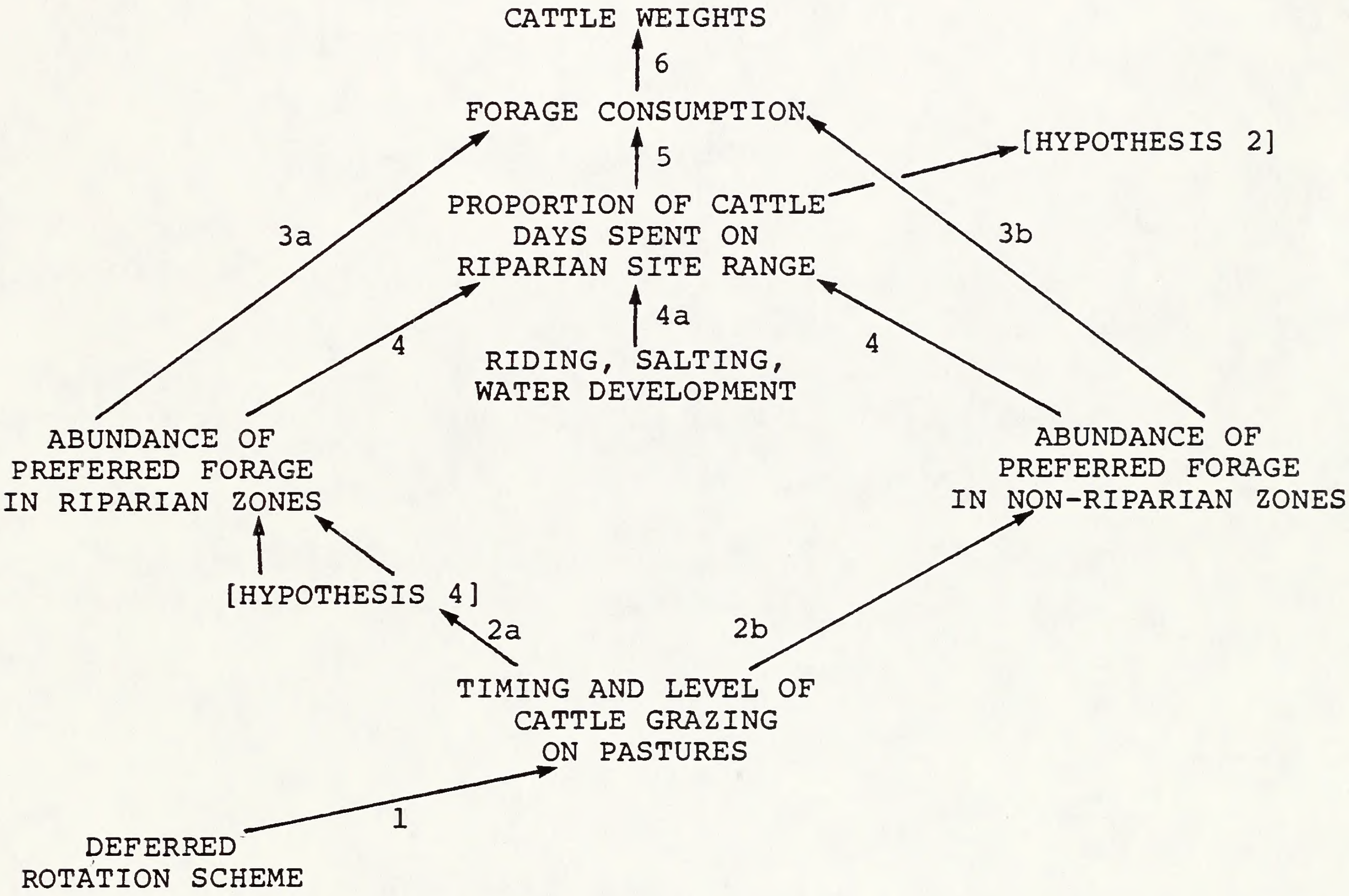
If the subgroup chose either (c) or (d) as a conclusion (for any of the hypothesis links), the necessary research activities were then discussed. Each subgroup's conclusions were evaluated by the other participants on the last day of the workshop.

The impact hypotheses and subgroup discussions are reported on the following pages. In examining these discussions, it is important to recognize that research on the Saval Ranch is conducted through a Memorandum of Understanding between the Bureau of Land Management, the Agricultural Research Service, the U.S. Forest Service, the Soil Conservation Service, the University of Nevada and the Saval Ranch. The following discussions do not specify who will actually be performing various research activities. Instead, we have focused on the actual research questions and methods used to answer them.

Finally, it should be understood that dividing a complex ecosystem into a set of linked impact hypotheses necessitates leaving out some ecological interactions. The intent of the impact hypotheses is not to represent all ecological relationships, but merely those which must be considered when evaluating the consequences of management actions.

6.1 The Effect of the Deferred Rotation Scheme and Other Management Actions on Cattle Weights

Hypothesis 1: *The deferred rotation scheme will increase the abundance of preferred forage on the Saval Ranch, leading to long term increases in cattle weights.*


CATTLE WEIGHTS
6
FORAGE CONSUMPTION
5
[HYPOTHESIS 2]
PROPORTION OF CATTLE DAYS SPENT ON RIPARIAN SITE RANGE
3a
3b
4
4a
4
RIDING, SALTING, WATER DEVELOPMENT
ABUNDANCE OF PREFERRED FORAGE IN RIPARIAN ZONES
ABUNDANCE OF PREFERRED FORAGE IN NON-RIPARIAN ZONES
[HYPOTHESIS 4]
2a
2b
TIMING AND LEVEL OF CATTLE GRAZING ON PASTURES
1
DEFERRED ROTATION SCHEME

Links

1. *The deferred rotation scheme (and other actions) affect the timing and level of cattle grazing on pastures.*

2a. *Changes in grazing patterns induced by the management plan increase the abundance of preferred forage in riparian zones (detailed in Hypothesis 4).*

2b. *Changes in grazing patterns induced by the management plan increase the abundance of preferred forage in non-riparian zones.*

3a. *Increased abundance of preferred forage in riparian zones increases forage consumption.*

3b. *Increased abundance of preferred forage in non-riparian zones increases forage consumption.*

4. *Changes in the distribution of preferred forage between riparian and non-riparian zones will affect the distribution of cattle grazing.*

4a. *Management actions will influence cattle distribution in pastures.*

5. *Changes in the proportion of cattle days spent on riparian sites will affect overall levels of forage consumption.*

6. *The amount of forage consumed affects cattle weights.*

Discussion

There is good, documented evidence for all of the following links:

1. *The deferred rotation scheme (and other actions) affect the timing and level of cattle grazing on pastures;*

2b. *Changes in grazing patterns induced by the management plan increase the abundance of preferred forage in non-riparian zones;*

3a. *Increased abundance of preferred forage in riparian zones increases forage consumption;*

3b. *Increased abundance of preferred forage in non-riparian zones increases forage consumption; and*

4a. *Management actions will influence cattle distribution in pastures.*

Link 2a. *Changes in patterns induced by the management plan increase the abundance of preferred forage in riparian zones.*

Generally, the evidence indicates that rest periods are required to improve preferred forage (e.g., this is especially true for upland sites. For riparian sites, the results may be similar for deferred and rest rotation.). Under the intended grazing scheme, rest periods will occur on BLM, but not on USFS land. Therefore, Link 2a will certainly be valid on BLM lands, but is unlikely to occur on USFS pastures.

Link 4. *Changes in the distribution of preferred forage between riparian and non-riparian zones will affect the distribution of cattle grazing.*

This hypothesis continues to be very controversial. On the one hand, participants stated that much evidence indicates that the distribution of cattle in riparian areas is not well correlated with the relative abundance of forage in riparian range sites. Although cattle generally prefer to use riparian areas as a source of food and shade, they still spend a lot of time in the riparian zone even after the food supply has been depleted.

On the other hand, although total forage production from riparian sites is less than the production from upland sites, a large proportion of consumed forage may come from riparian areas. For example, Roath and Krueger (JRM: 100-103, 1982) found that a riparian zone occupied 1.9% of a pasture and produced about 21% of the available forage in the pasture, but accounted for 81% of the herbaceous vegetation removed by cattle. Some of the Saval Ranch Project fecal analyses (Winer) suggest that cattle obtained up to 88% of their diet from the wet meadow site that occupies about 1% of the area.

Existing data can be used to check the assumption that cattle use riparian range sites for reasons other than a food source. Data on diet composition (Winer) and forage biomass (Eckert/Staiger) could be analyzed to test whether the distribution of cattle forage consumption between riparian and non-riparian range sites is different from the distribution of available forage. It would be valuable to test this hypothesis on all pastures with sufficient data, recognizing that riparian use changes seasonally.

Link 5. *Changes in the proportion of cattle days spent on riparian sites will affect overall levels of forage consumption.*

This link could be tested by using existing utilization and production data in riparian and non-riparian areas to compare the amount of forage consumed. In equation form:

$$TC_i = PD_i * A_i * (PU_i/100) \qquad (6.1)$$

where,

TC_i = estimated total forage consumption in zone i (i = 1 for riparian; i = 2 for non-riparian), in lbs.;

PD_i = measured production of forage in zone i (lbs/a);

A_i = area (a) of zone i, within the pasture; and

PU_i = measured overall percent utilization in zone i.

If TC_1 (riparian) is very much less than TC_2 (upland), then it is unlikely that management-induced changes in the proportion of cattle days spent on riparian sites will be large enough to cause measurable, significant changes in overall forage consumption ($TC_1 + TC_2$). As the ratio of TC_1 to TC_2 increases, so does the probability that link 5 will be valid.

Conclusions

It is possible that the grazing management plan will affect cattle weights by changing the abundance of preferred forage in riparian range sites. However, it will be impossible to detect this effect. Though there is some debate (see discussion after link 4), it is generally felt that riparian forage makes up only an extremely small percentage of cattle diets. If so, any effects on the availability of forage on riparian sites may be confounded both by the effects of the management plan on upland sites, and the greater variability of forage abundance on these non-riparian sites. Thus, the issue is not whether the potential exists to increase cattle forage intake from the riparian zone, but whether the management schemes will produce a sufficient increase that can be measured with a sufficient degree of confidence.

The hypothesis that redistribution techniques will affect the number of cattle use days in riparian zones (4a) is testable with modifications to existing research, as outlined below. The rationale for performing such research is not merely to document the effect of redistribution techniques on cattle utilization (which has been done elsewhere), but to also demonstrate the indirect effects of such manipulations on riparian vegetation, channel morphology and aquatic habitat (as outlined in Hypothesis 2).

Recommended Research

Quantitative observations of cattle distribution have been taken during the last two years in the south Forest Service pasture, where there are no manmade water sources. These data form a baseline. If water developments were added to part of this pasture, one could test the hypothesis that water developments reduce cattle use of riparian areas, with a consequent improvement in riparian habitat generally. Data on cattle use, streamside vegetation and channel morphology could be examined (via multi-way analyses of variance) to look for the effects of the:

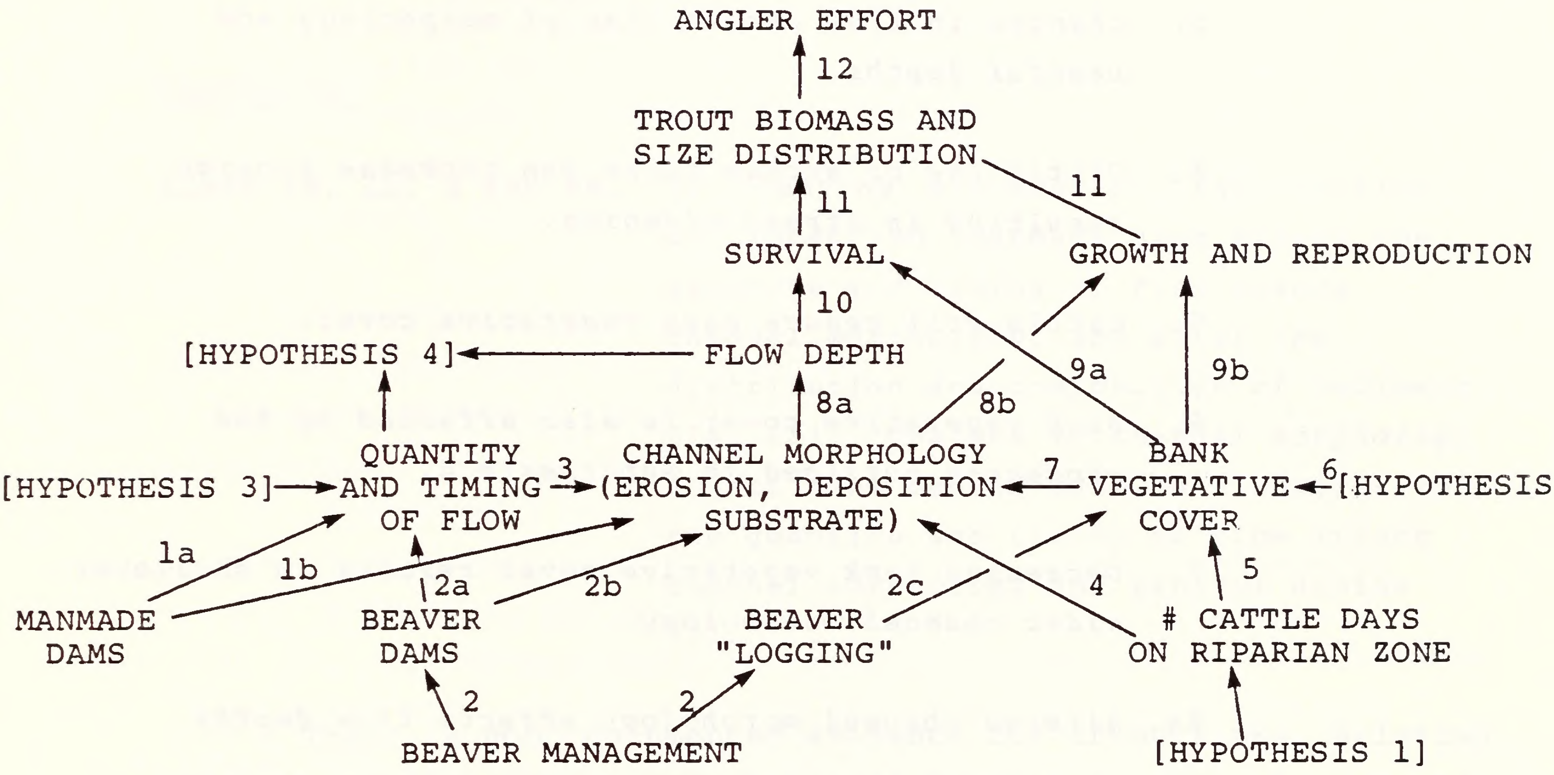
- presence (versus absence) of manmade water sources;
- presence (versus absence) of natural water sources;
- distance to manmade water sources; and
- season of use.

Obviously, this work would need to be carefully integrated with ongoing fisheries research. It would also be valuable to examine how cattle distribution varies with the age, size and breed of animal.

On the final day of the workshop, it was suggested that microhistological analysis could be used to quantify the proportion of cattle diet that is made up by riparian forage, and the seasonal variability in that proportion. Such analyses would probably help to explain observed utilization patterns.

6.2 The Effects of Dams, Beaver Management and Cattle Grazing on Trout

Hypothesis 2: *Building dams, beaver management and cattle grazing can affect trout biomass and size distribution.*



Links

1a. *By changing evaporation, infiltration and retention, manmade dams affect the quantity and timing of flow.*

1b. *Manmade dams change channel morphology, and sediment distribution and composition.*

2. *Management of beavers can control the number of beaver dams and extent of vegetation removed by beavers.*

2a. *Beaver dams affect the quantity and timing of flow.*

2b. *Beaver dams affect channel morphology, and sediment distribution and composition.*

2c. *Beavers reduce bank vegetative cover.*

3. *Changes in flow affect channel morphology and bankful depths.*

4. *Cattle use of stream banks can increase erosion resulting in stream widening.*

5. *Cattle will reduce bank vegetative cover.*

6. *Bank vegetative cover is also affected by the processes outlined in Hypothesis 4.*

7. *Decreased bank vegetative cover results in shallower, wider channel morphology.*

8a. *Altered channel morphology affects flow depths.*

8b. *Altered channel morphology can decrease trout reproduction by depositing fine sediments on spawning areas.*

9a. *Reductions in bank vegetative cover decrease trout survival.*

9b. *Reductions in bank vegetative cover decrease trout growth and reproduction (through increased temperatures and increased vulnerability to predation and storm flows).*

10. *Reduced flow depths decrease survival of all life stages of trout.*

11. *Trout biomass and size distribution is determined by survival, growth and reproduction.*

12. *Angler effort responds to trout abundance (# trout > 6" long).*

Discussion

Links la, lb, 3 and 8a. *By changing evaporation, infiltration, and retention, manmade dams affect the quantity and timing of flow change channel morphology, and alter the distribution and composition of sediment (la, lb). Changes in channel morphology affect flow depths (9a), and changes in the quantity and timing of flow affect channel morphology and bankful depths (3).*

There is good documented evidence for these links. Existing computer models (ERHYM, SRM, National Weather Service, Army Corps of Engineers, etc.) and others under development simulate links la, lb and 8a. Application of some of these models to Gance and Mahala is under way.

Qualitative and quantitative techniques exist for predicting the effects of flow changes on channel morphology and bankful depths (link 3). Supplementing existing stream channel records and infiltration studies with additional information would make it possible to apply these relationships to Gance and Mahala Creeks.

Link 2. *Management of beavers can control the number of beaver dams and extent of vegetation removed by beavers.*

The subgroup concluded that the state-of-the-art of beaver management was uncertain, and that a literature review should therefore be undertaken to assess this link.

Links 2a, 2b, and 2c. *Beaver dams affect the quantity and timing of flow, channel morphology, and sediment distribution and composition. Beavers reduce bank vegetative cover.*

The participants were only aware of qualitative information regarding these links. They concluded that there is a need for quantitative data on hydrological and vegetation effects of beavers, through both expanded literature searches and field studies.

Links 4 and 5. *Cattle use of stream banks can increase erosion (resulting in stream widening) and reduce bank vegetative cover.*

Though some data is available to address this hypothesis, cattle utilization is not quantified in most studies. Some cattle use is beneficial and helps to thin out stabilizing vegetation. Platts' data indicates that 25 - 40% utilization is acceptable once stream bank vegetation is restored, though lower utilization is necessary to allow recovery in damaged areas. The experimental design of Platts' study was reviewed and considered satisfactory for testing this hypothesis except that some of the fences aren't working and need to be reinforced. Also, if cattle utilization was more precisely measured generally, it might be possible to determine whether channel widening was due to the direct effects of cattle trampling banks (link 4) or due to changes in bank vegetative cover (as a result of hydrological factors or grazing - link 7).

Link 7. *Decreased bank vegetative cover results in shallower, wider channel morphology.*

This has been well documented in the literature.

Link 8b. *Altered channel morphology can decrease trout reproduction by depositing fine sediments on spawning areas.*

Links 9a and 9b. *Reductions in bank vegetative cover decrease trout survival, growth and reproduction through increased temperatures and increased vulnerability to predation and storm flows).*

Link 10. *Reduced flow depths decrease survival of all life stages of trout.*

Effects on fish populations are easier to detect in more stable creeks (e.g., Taylor) than in Gance Creek where stream volatility induces great variability in growth, survival and reproduction. This variability demands a long period of intensive sampling in order to demonstrate that certain stream sections are significantly different from others.

Link 11. *Trout biomass and size distribution is determined by survival, growth and reproduction.*

Though this hypothesis is tautological (true by the way it is stated), the volatility of Gance and Mahala make it very difficult to demonstrate precisely which parameters are changing. In general, trout biomass and size distribution are less variable than growth, survival and reproduction.

Link 12. *Angler effort responds to trout abundance (# trout > 6" long).*

Angler effort is not measured on the Saval Ranch, and participants were not aware of any studies from similar semi-arid regions.

Conclusions

All links affecting trout survival, growth and reproduction (8b, 9a, 9b, 10) were considered too hard to detect in Gance and Mahala. It was suggested that benthic invertebrates may be more worthwhile as indicators of stream condition, though the correlation between changes in benthos and changes in fish population parameters is weak. The subgroup felt that the best approach was to look for the effects of changes in flow depth and bank vegetative cover at the level of fish biomass and size distributions (i.e., merge links 8b, 9a, 9b and 10 with link 11). Coordination with the Nevada Department of Wildlife stocking and electroshocking program is important, both to bookkeep numbers of fish and to improve sample sizes. Since fishing activity is sparse and infrequent, monitoring angler effort (link 12) was rejected as being infeasible.

It was concluded that new field studies should be undertaken to examine the effects of beavers (links 2, 2a, 2b and 2c). A preliminary design for these studies is outlined below.

Recommended Research

The hydrological and vegetation effect of beavers would make appropriate topics for graduate student projects. Ideally, there would be four treatments, each along 0.5 miles of creek, repeated on Gance and Mahala Creeks:

1) neither beavers nor cattle grazing;

2) beavers only;

3) cattle only; and

4) both beavers and cattle.

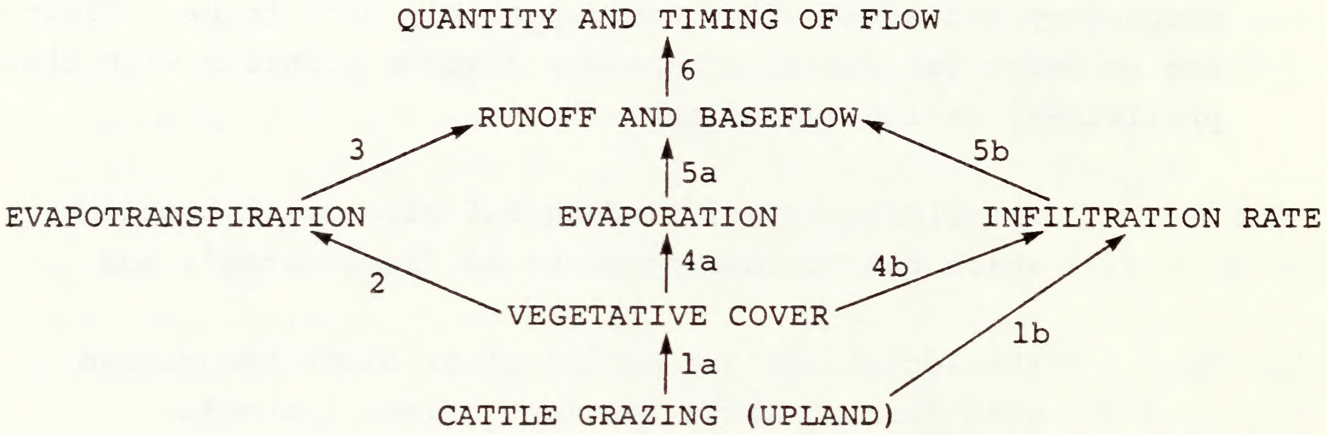
Fences would have to be used to create treatments 1 and 2, which do not currently exist on the Saval Ranch. To document linkages 2, 2a, 2b, and 2c, data on bank vegetative cover, channel morphology and stream flow would probably need to be collected for at least ten years. There are obvious problems with this preliminary design including:

- the difficulty of finding 0.5 mile creek sections which can be considered to be "replicates"; and
- the logistical and political problems associated with fencing large sections of the two major creeks on the Saval Ranch.

Prior to even considering these problems, prospective researchers should conduct a thorough review of published and unpublished (e.g., Park Service) literature. If such a study is implemented, it could be of great value to research studies on fisheries, vegetation, deer, sage grouse and non-game birds. For that value to be realized, the linkages between the experimental designs of different researchers must be pre-planned. Such planning may result in significant changes to the preliminary experimental design described above. For example, it may be preferable to compare grazing under the AMP with a control grazing treatment, rather than no grazing.

6.3 Effects of Cattle on Quantity and Timing of Flow

Hypothesis 3: *Cattle grazing will affect the quantity and timing of flows by affecting evaporation, evapotranspiration and infiltration rates.*



Links

1a. *Grazing and trampling reduce vegetative cover and alter its composition.*

1b. *Cattle trampling influences infiltration.*

2. *Reduced vegetative cover results in lower evapotranspiration.*

3. *Low evapotranspiration rates in the upper watershed result in higher baseflows.*

4a and 4b. *Reduced vegetative cover increases evaporation rates and reduces the infiltration rate.*

5a and 5b. *Lower infiltration and higher evaporation rates can cause lower baseflows (depending on groundwater) with the reduction being greater than the increase via link 3. Lower infiltration rates can also increase peak flow.*

6. *Runoff and baseflow drive flow.*

Discussion

The effects of upland cattle grazing on vegetative cover and infiltration rate (links 1 and 1a) are generally understood, but not well documented quantitatively. The remaining links are documented in existing models, which generally work if the parameters are accurately measured.

Conclusion

On the Saval Ranch, there is much annual variability in driving variables (e.g., temperature, precipitation, solar radiation) and a wide mixture of grazing intensities within given watersheds. This makes it impossible to demonstrate that the quantity and timing of flow within a whole watershed is affected by upland cattle grazing, even if the extensive instrumentation required was installed (Conclusion (b); see list in Section 6.0). However, small, controlled experimental catchments could potentially demonstrate such effects, with the results then extrapolated. This would involve some new research (Conclusion (c)) and some changes to existing studies (Conclusion (d)), as outlined below.

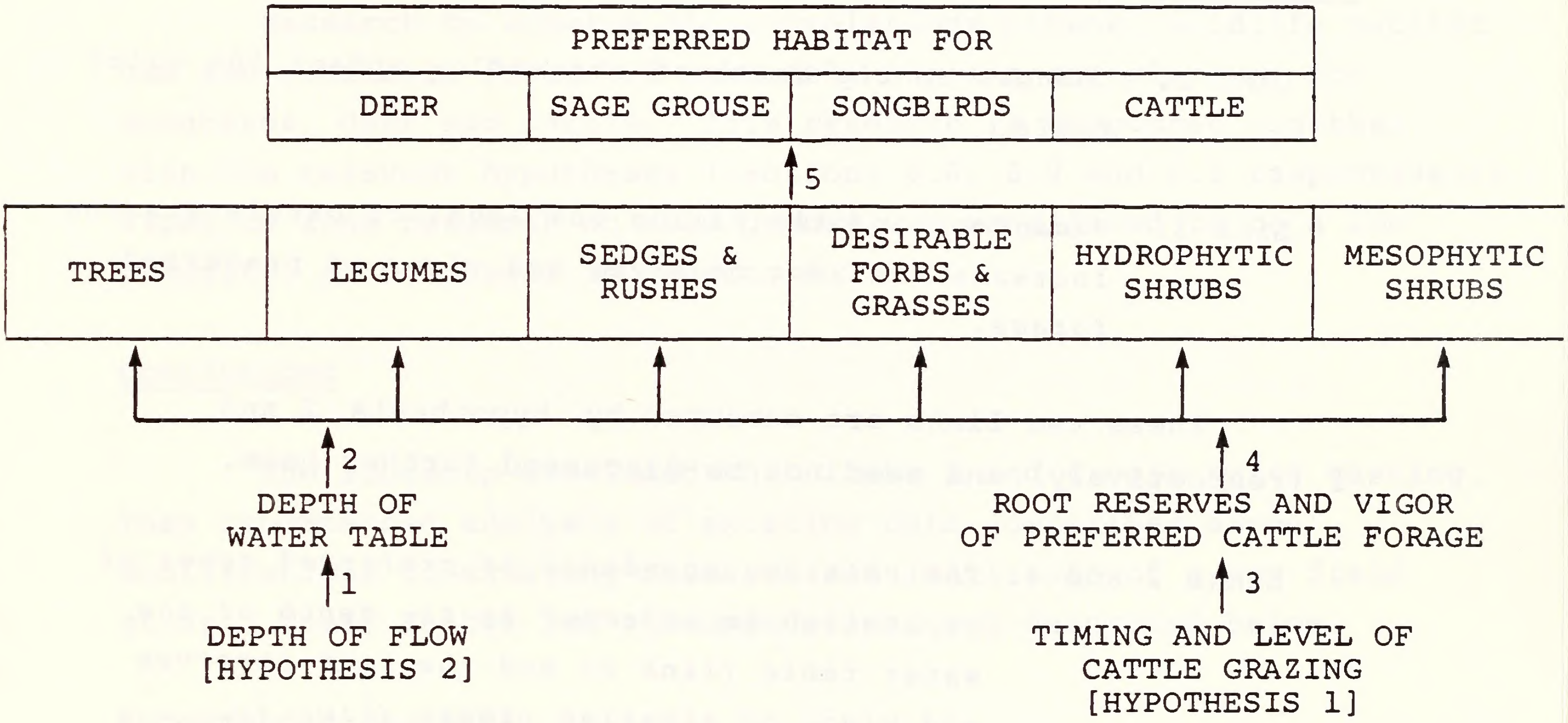
Recommended Research

Participants were not certain about the exact location of the two catchments that are currently being monitored. Therefore, it is not clear to what extent they are appropriate for the research described below. It would be valuable, however, to examine the variability in runoff (and perhaps baseflow) in the existing data from these catchments.

The recommended approach to testing hypothesis 3 is to apply different grazing treatments (season long; deferred; rest rotation) to small (10a) catchments. To test the hypothesis, one would need to measure all of the components shown in the diagram for this hypothesis, as well as percent bare ground and soil moisture. The results from these 10a plots would then be extrapolated to whole watersheds using existing data and literature values for uncertain parameters. Examination of the variability in runoff in the two currently monitored catchments would assist in the experimental design (number of replicates, length of experiment, etc.). Simulation models which combine runoff variability with other sources of variability (e.g., temperature, solar radiation, cattle grazing patterns) would permit researchers to perform a more thorough assessment of the required extent and duration of the study.

6.4 Effect of Changes in Stream Flow and Cattle Grazing on Preferred Forage

Hypothesis 4: *Changes in the depth of stream flow and the timing and level of grazing affect the abundance of preferred plants for deer, cattle, sage grouse and songbirds.*


PREFERRED HABITAT FOR
DEER
SAGE GROUSE
SONGBIRDS
CATTLE
5
TREES
LEGUMES
SEDGES & RUSHES
DESIRABLE FORBS & GRASSES
HYDROPHYTIC SHRUBS
MESOPHYTIC SHRUBS
2
DEPTH OF WATER TABLE
1
DEPTH OF FLOW [HYPOTHESIS 2]
4
ROOT RESERVES AND VIGOR OF PREFERRED CATTLE FORAGE
3
TIMING AND LEVEL OF CATTLE GRAZING [HYPOTHESIS 1]

Links

1. *Changes in the depth of streamflow affect the water table.*

2. *The relative abundance of preferred and unpreferred types of vegetation is affected by the depth of the water table.*

3. *Management of the timing and level of cattle grazing increases the root reserves and vigor of preferred forage.*

4. *Increased root reserves and plant vigor result in increased abundance of preferred forage in mountain and alluvial riparian areas.*

5. *Habitat suitability for deer, sage grouse, songbirds and cattle is strongly affected by the abundance of preferred forage.*

Discussion

Link 1. *Changes in the depth of streamflow affect the water table.*

Link 3. *Management of the timing and level of cattle grazing increase the root reserves and vigor of preferred forage.*

These two links are subsumed by hypothesis 2 and 1 (respectively) and need not be discussed further here.

Links 2 and 4. *The relative abundance of preferred types of vegetation is affected by the depth of the water table (link 2) and the root reserves and vigor of riparian plants (link 4).*

These links are poorly supported by research on Saval but are conceptually reasonable and generally supported by data from elsewhere. These questions could be investigated further by a fresh analysis of existing data. The first need is to decide whether plant abundance is more strongly affected by soil moisture content and water table levels (link 2) or by forage consumption patterns (link 4). It may be possible to subjectively classify the soil moisture content of sites on which vegetation frequency measurements have already been made (i.e., Dr. Eckert's riparian meadow monitoring plots). Comparisons of plant species composition among sites with different moisture contents can then be made. If plant species composition differ greatly among, but not within, these sites, it may be assumed that direct effects of changes in forage consumption (link 4) might be masked by effects of soil moisture change (link 2). This would suggest the need for experiments to clarify link 2.

Link 5. *Habitat suitability for deer, sage grouse, songbirds and cattle is strongly affected by the abundance of preferred forage.*

Research to examine the correlations between wildlife habitat use and available forage is currently ongoing (or planned) for songbirds, deer and cattle. This research is discussed together with the relevant hypotheses (Sections 6.6, 6.9 and 6.1 respectively). Riparian zone research on sage grouse was considered to be a low priority, as discussed in Section 6.7.

Conclusions

The subgroup concluded that links 2 and 4 were worth testing. They recommended analysis of existing data (described above), modifications to existing research and initiation of a new field study. These latter two recommendations are described below.

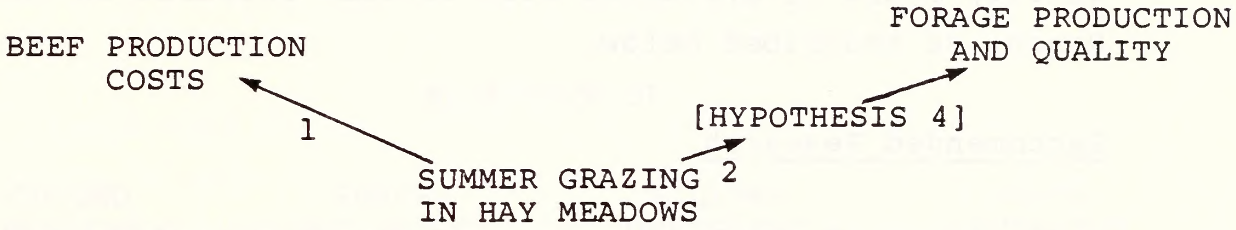
Recommended Research

Further evaluations of links 2 and 4 could be obtained by modifying the existing study plan. Researchers could take simultaneous vegetative and soil moisture measurements both across and parallel with the observed vegetation gradient (i.e., among and within similar vegetation "types") to look for correlations between soil moisture and abundance of trees, legumes, desirable forbs and grasses, etc. Grazing test and control sites would be needed to accompany these measurements.

The beaver management study (described in Section 6.2) could include a cooperative research program with two graduate students. One student would study relationships between soil moisture and vegetative composition and abundance. The other would evaluate effect of change in stream channels on soil moisture and water table. As was mentioned for hypothesis 3, there is a strong need to look at the variability in existing data, so as to ensure that both current and new research plans contain adequate numbers of replicates. For vegetation data, it would be valuable to know the variation in percent occurrence of different species (both spatially (distance from stream) and in relation to soil moisture gradients).

6.5 Effects of Summer Grazing on Hay Meadows

Hypothesis 5: *Summer grazing on the hay meadows* will decrease beef production costs and increase forage production and quality.*



Links

1. *Summer grazing on hay meadows will decrease beef production costs.*

2. *Summer grazing on hay meadows will increase forage production and quality.*

Discussion

Economic analyses suggest link 1 is valid because:

1) Saval cattle wintering costs would decrease if they were shipped to wintering range in the south; and

2) there would be greatly reduced haying costs.

However, the extent of net savings are dependent on how the Saval Ranch would be paid for grazing of the hay meadows (i.e., per head, or according to weight gain).

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* Under this scheme, Saval animals would be shipped south for the winter, and southern animals shipped north in the summer.

There is evidence for link 2 as well, although the evidence is primarily for irrigated and/or fertilized meadows.

Conclusion

The effects of summer grazing on forage production and quality could be evaluated with further research on the Saval Ranch, as described below.

Recommended Research

Part of the hay meadow would be kept under existing management practices to serve as a control. The remaining parts of the meadow would receive summer grazing, with some form of deferred rotation in effect. Fertilization could be considered as an additional treatment. The following variables would be measured annually for five years on a set of plots within each treatment:

1) forage production;

2) crude protein;

3) crude fiber; and

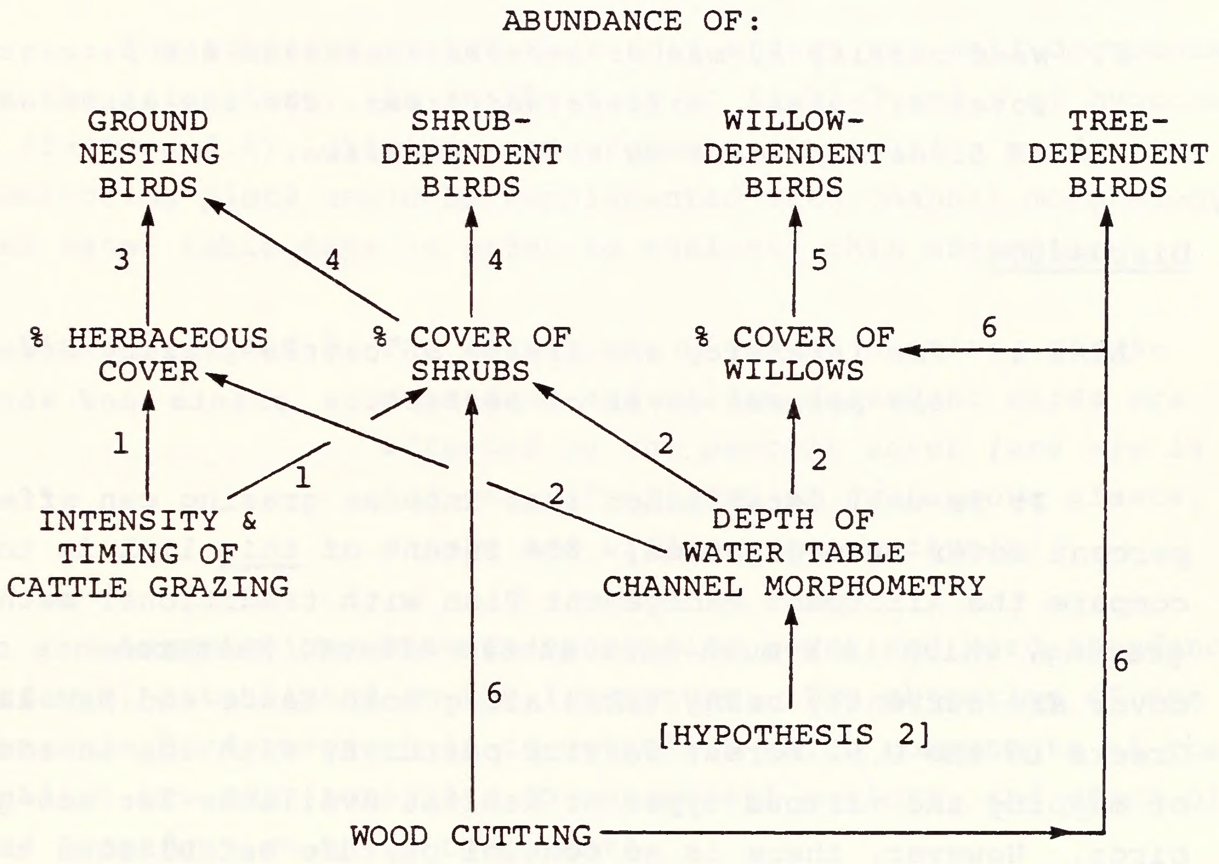
4) soil bulk density.

It was felt that five years would be sufficient to detect changes between treatment and control, irrespective of weather effects. If after five years there are no between treatment differences, the hypothesis is falsified.

This study would also provide an opportunity to compare the nutritional effects of a hay diet (as evident in cattle information collected over the last three years) with the forage consumed on southern ranches over winter (under the proposed scheme). Clearly, not all southern ranches are created (or maintained) equal.

6.6 Effects of Cattle Grazing, Wood Cutting and Channel Morphology on Non-Game Birds

Hypothesis 6: *Changes in the intensity and timing of cattle grazing and the depth of channel cutting affect the abundances of non-game bird populations.*



Links

1. *The intensity and timing of cattle grazing effects the percent cover of shrubs and herbaceous plants.*

2. *Channel morphometry and water table depth affect the percent cover of herbaceous plants, shrubs, and willows.*

3. *The abundance of ground nesting birds increases with percent herbaceous cover.*

4. *The percent cover of shrubs affects the abundance of ground nesting and shrub dependent birds.*

5. *The abundance of willow dependent birds increases with the percent cover and age of willows.*

6. *Wood cutting by man or beavers decreases the percent cover of shrubs, willows and trees, and the abundance of birds dependent on this vegetation.*

Discussion

Link 1. *The intensity and timing of cattle grazing affects the percent cover of herbaceous plants and shrubs.*

It is well established that intense grazing can affect the percent cover of vegetation; the intent of this link is to compare the Allotment Management Plan with traditional methods of grazing, which is a much more subtle effect. Measurements of percent cover are currently being taken along both Gance and Mahala Creeks in the U.S. Forest Service pastures, with the intention of mapping the various types of habitat available for non-game birds. However, there is no control pasture established to allow comparisons of the vegetation cover across different grazing treatments. In the BLM riparian zones (which consist primarily of stringer meadows), a control pasture exists and percent cover measurements are being taken by vegetation scientists. Over time, this data should reveal whether the Allotment Management Plan alters vegetation cover from that observed under traditional grazing. Participants doubted that such an effort will be observed for shrubs, though effects on herbaceous cover may be strong enough to be detected statistically. Scientists studying the habitat of non-game birds use some measures of vegetation structure that are not typically measured by vegetation scientists (e.g., vertical structure measurements of shrubs and trees). If data on these supplementary variables is desired, it is critical that the two groups of scientists coordinate the locations and methods of data collection.

Link 2. *Channel morphometry and water table depth affect the percent cover of herbaceous plants, shrubs and willows.*

The subgroup stated that this effect was well documented in the literature. As in the case of links 2 and 4 of hypothesis 4 (Section 6.4), existing measurements in riparian meadow monitoring plots could be supplemented with channel morphology and water table data in order to evaluate this assumption.

Links 3, 4 and 5. *The abundances of ground nesting, shrub-dependent and willow-dependent birds are affected by the percent cover (and age in the case of willow) of herbaceous plants, shrubs and willows (respectively).*

Associations between vegetation cover and bird abundance are well established in the literature. The objective of the non-game bird reserach is to establish which components of the habitat are most sensitive to management actions, and which birds are dependent on those components.

On the Forest Service pastures, vegetation cover and bird abundance variables have been measured on both Gance and Mahala Creeks. Comparisons between creeks have indicated significant differences in both groups of variables. However, because of within creek variation in both drainage and cover, the vegetation-bird relationships are not entirely clear. To clarify these relationships, it will be necessary to take transects of bird abundance across riparian zones (e.g., with a contrast in percent cover and age of willows).

Non-game bird research has concentrated on the Forest Service pastures which have more habitat structure and are considered to be more "typically riparian". The subgroup concluded that the research should be expanded to the BLM stringer meadows, which offer several advantages:

1) existence of a control pasture;

2) fewer species to monitor;

3) land owned by the major funding agency; and

4) a habitat type which is common to northwest Nevada, and has not previously been studied on the Saval.

Link 6. *Wood cutting by beavers decreases the percent cover of shrubs, willows and trees, and the abundance of birds dependent on this vegetation.*

The impacts of beaver activity on bird populations are not well understood, and could be examined as part of the beaver study described under hypothesis 2 (Section 6.2). Also, it is possible that beaver activity might increase young shrub cover since it removes some of the older material.

Conclusions

Links 1, 2 and 6 concern the impacts of cattle grazing, wood cutting and stream channel changes on components of the habitat used by birds. The subgroup concluded that these hypotheses could be tested on the Saval Ranch with a few modifications to existing research plans, and some additional studies. These research changes are described below.

Links 3, 4 and 5 concern the effect of habitat changes on bird populations. There are two ways of testing these hypotheses:

1) by monitoring bird populations over a long period of time on sites where habitat change is anticipated; and

2) by comparing bird populations across a number of sites with contrasting habitat (i.e., where habitat change has already occurred).

The second approach is the one currently being used, and the one recommended by the subgroup. With some changes to the design and scope of the current study, links 3, 4 and 5 should be testable on the Saval Ranch.

Research Recommendations

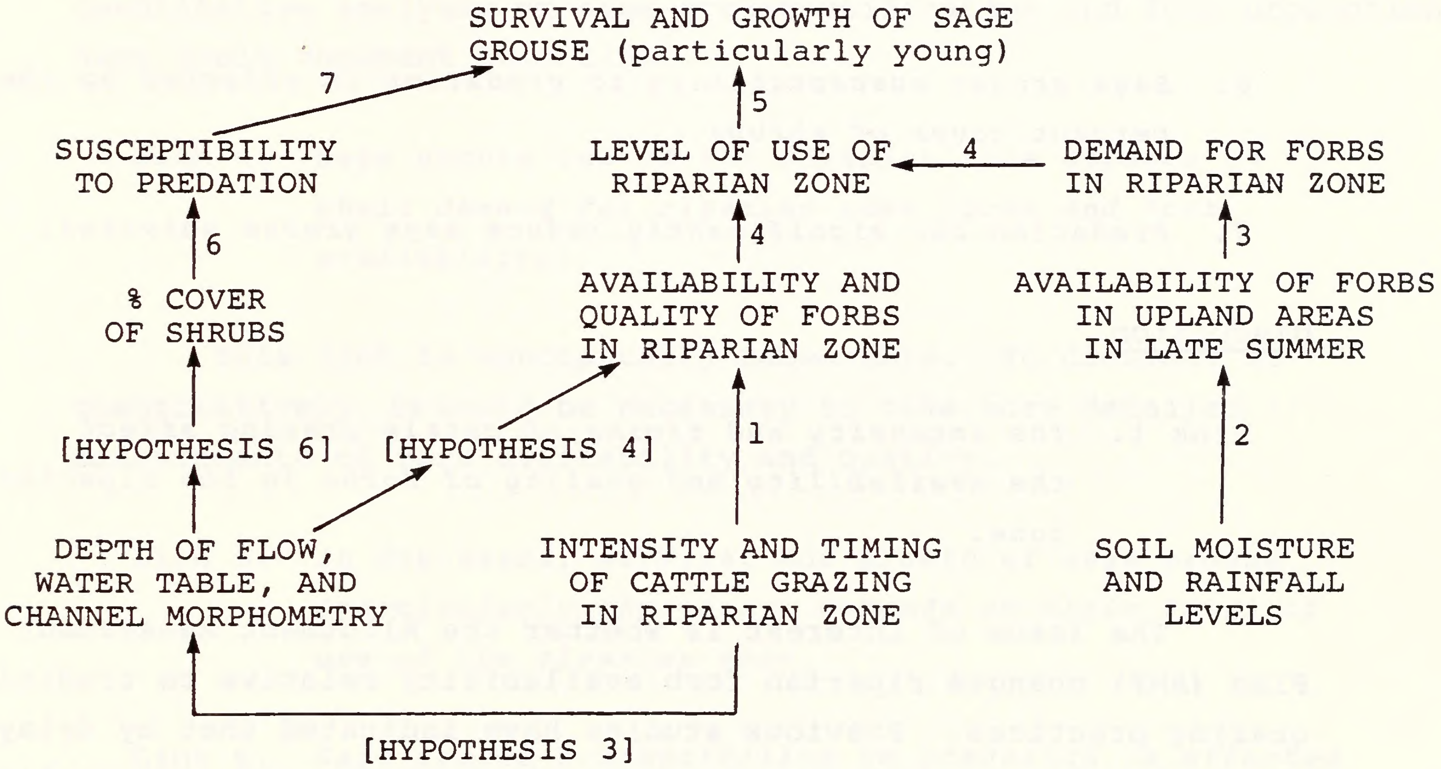
To assess whether grazing under the Allotment Management Plan affects herbaceous and shrub cover differently from traditional grazing practices (link 1), it will be necessary to have adequate controls in place on both the BLM and Forest Service pastures, for a full grazing cycle. To demonstrate that observed shifts in vegetation cover were due to grazing and not to changes in water table depths or channel morphometry (link 2), hydrological/ geomorphological variables also must be monitored at the vegetation sampling sites. Grazing treatment effects are more likely to be detected along stream reaches where channel cutting has not occurred.

The effects of beavers on vegetation cover (link 6) also interact with hydrological variables. If the beaver study does take place, close interdisciplinary coordination will be essential.

Studies addressing links 2, 4 and 5 should show changes in the abundances of certain bird species as a function of habitat variables that are directly or indirectly affected by grazing. The strategy of the bird researchers should therefore be to find a series of sites which represent the range of habitat conditions observed under grazing (i.e., simulating spatially the changes that occur through time). Control pastures are not necessary for studies of habitat gradients, but it is important that the sites be carefully selected so that confounding variables are either eliminated or controlled. If trend-through-time monitoring of bird populations is being considered, then controls are essential.

6.7 Responses of Young Sage Grouse to Riparian Grazing, Upland Soil Moisture Levels, and Stream Condition

Hypothesis 7: *In dry years, the survival and growth of sage grouse are affected by the intensity and timing of cattle grazing in the riparian zone.**


SURVIVAL AND GROWTH OF SAGE GROUSE (particularly young)
7
5
SUSCEPTIBILITY TO PREDATION
LEVEL OF USE OF RIPARIAN ZONE
4
DEMAND FOR FORBS IN RIPARIAN ZONE
6
4
3
% COVER OF SHRUBS
AVAILABILITY AND QUALITY OF FORBS IN RIPARIAN ZONE
AVAILABILITY OF FORBS IN UPLAND AREAS IN LATE SUMMER
[HYPOTHESIS 6]
[HYPOTHESIS 4]
1
2
DEPTH OF FLOW, WATER TABLE, AND CHANNEL MORPHOMETRY
INTENSITY AND TIMING OF CATTLE GRAZING IN RIPARIAN ZONE
SOIL MOISTURE AND RAINFALL LEVELS
[HYPOTHESIS 3]

Links

1. *The intensity and timing of cattle grazing affect the availability and quality of forbs in the riparian zone.*

2. *Late summer availability of forbs in upland areas varies with soil moisture and rainfall levels.*

---

*Those links discussed under other hypotheses are not treated here.

3. *Sage grouse demand for forbs in the riparian zone varies inversely with forb availability in upland areas.*

4. *Sage grouse use of the riparian zone depends on their demand for riparian zone forbs, and forb availability.*

5. *In dry years, survival and growth of sage grouse (particularly the young) depends on their level of use of the riparian zone.*

6. *Sage grouse susceptibility to predation is affected by the percent cover of shrubs.*

7. *Predation can significantly reduce sage grouse survival.*

Discussion

Link 1. *The intensity and timing of cattle grazing affect the availability and quality of forbs in the riparian zone.*

The issue of interest is whether the Allotment Management Plan (AMP) changes riparian forb availability relative to traditional grazing practices. Previous studies have indicated that by delaying plant phenology, cattle grazing prevents browning and accumulation of litter, and is therefore beneficial to forbs. Studies also indicate, however, that forb availability can improve as a result of rest rotation. The subgroup felt that differences between the AMP and traditional grazing would be subtle, and would likely only be evident in the BLM pastures (since they are under rest rotation). Under the current study design, effects could, in any case, only be detected on BLM land, since USFS land has no control pastures.

Link 2. *Late summer availability of forbs in upland areas varies with soil moisture and rainfall levels.*

Link 3. *Sage grouse demand for forbs in the riparian zone varies inversely with forb availability in upland areas.*

Good evidence exists for these two links from existing data. The dryness of 1981 contrasted sharply with the above average moisture of 1982 and 1983, and this contrast was reflected in both upland forb availability and sage grouse use of riparian meadows. Quantitative analysis of sage grouse utilization and forb production data could document this link.

Link 4. *Sage grouse use of the riparian zone depends on their demand for riparian zone forbs and forb availability.*

This link is conceptually reasonable. To document it quantitatively, it would be necessary to take more detailed measurements of forb availability and quality.

Link 5. *In dry years, survival and growth of sage grouse (particularly the young) depends on their level of use of the riparian zone.*

Link 6. *Sage grouse susceptibility to predation is affected by the percent cover of shrubs.*

Link 7. *Predation can significantly reduce sage grouse survival.*

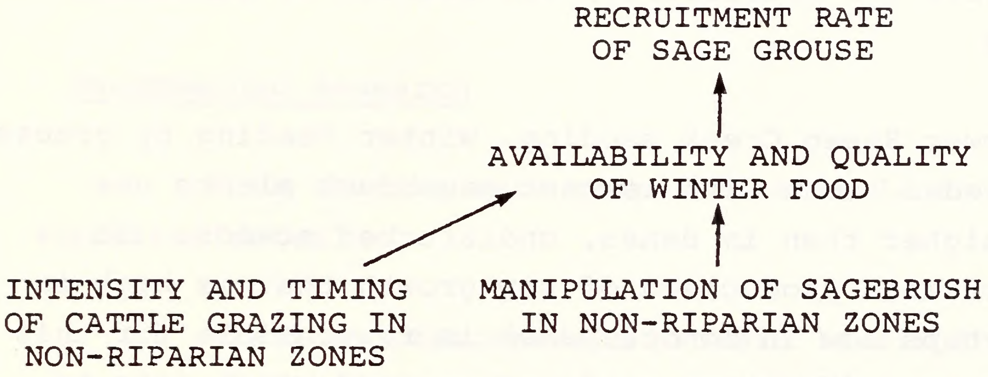
Changes in survival and growth are too hard to detect, due to small population sizes and the large amount of effort required to determine which predator was responsible (links 5 and 7). The effect of shrub cover on susceptibility to predation (link 6) varies with the predator. During the day, high shrub cover in riparian feeding areas is advantageous in avoiding avian predators. At night, sage grouse prefer to roost in open areas with low percent shrub cover, where approaching coyotes can be seen. The difficulties of monitoring predation suggest that it is not worthwhile testing link 6 as part of the Saval research.

Conclusions

Unless the riparian vegetation is degraded by long term changes in the soil moisture regime (hypothesis 4; Section 6.4), the grazing plan probably will not cause measurable changes in forbs in the riparian zone. Therefore, testing of this hypothesis should be deemphasized.

6.8 Responses of Female Sage Grouse to Cattle Grazing and Sagebrush Removal

Hypothesis 8: *The recruitment rate of sage grouse is affected by cattle grazing (its intensity and timing) and sagebrush removal actions (their level and pattern).*


RECRUITMENT RATE OF SAGE GROUSE
AVAILABILITY AND QUALITY OF WINTER FOOD
INTENSITY AND TIMING OF CATTLE GRAZING IN NON-RIPARIAN ZONES
MANIPULATION OF SAGEBRUSH IN NON-RIPARIAN ZONES

Links

1. *The intensity and timing of cattle grazing in non-riparian zones affects the availability and quality (protein content, monoterpenes) of sagebrush food sources for sage grouse.*

2. *Removal of sagebrush by chaining or other actions affects the availability and quality of sagebrush food.*

3. *The availability and quality of sage grouse winter food strongly affects recruitment.*

Discussion

Link 1. *The intensity and timing of cattle grazing in non-riparian zones affects the availability and quality (protein content, monoterpenes) of sagebrush food sources for sage grouse.*

There is little evidence that intensity and timing of cattle grazing will affect availability and quantity of winter food for sage grouse, although the long term effect of intense grazing is to increase the abundance of sagebrush. Differences in the abundance of sagebrush due to grazing alone (between the AMP and control pastures) are likely to be negligible over the twelve year cycle.

Link 2. *Removal of sagebrush by chaining or other actions affects the availability and quality of sagebrush food.*

In the Lower Sheep Creek seeding, winter feeding by grouse in plowed and seeded areas with remnant sagebrush plants was observed to be higher than in dense, undisturbed stands. It is assumed that increased production of new growth that is high in protein (and perhaps low in monoterpene) is responsible for this apparent preference. (Monoterpene is a compound which acts to discourage herbivore feeding. It is believed that there is a monoterpene threshold below which sage grouse select plants with the highest protein levels.)

Link 3. *The availability and quality of sage grouse winter food strongly affects recruitment.*

Existing hunter-check station data indicate that approximately half of the female grouse in the region do not produce eggs. (Though sample sizes from Saval are small (< 20 birds/year), the regional sample is large (> 200 birds/year), so the 50% figure is reasonable (Back, pers. comm.).) Since grouse gain weight in late winter and early spring (perhaps as a prelude to breeding and laying), it is likely that the quality and quantity of winter food can affect recruitment. Even in a "healthy" population, some females may not assimilate sufficient protein and other nutrients to produce eggs.

Conclusions

It was concluded that link 1 (effects of grazing on sagebrush food) was unlikely and not worth testing.

Since the effect of sagebrush removal on sage grouse is an issue of great interest to managers of both rangelands and sage grouse, and previous observations lend support to the hypotheses, it was concluded that links 2 and 3 should be tested via additional research.

Recommended Research

Five studies were proposed to evaluate links 2 and 3 in greater detail:

1) track monoterpene and protein levels in grouse food plants (several sage species) throughout the year;

2) compare monoterpene and protein levels in plants from grouse feeding sites to those in plants collected randomly;

3) try to alter monoterpene levels in plants by experimental thinning of sagebrush stands and by simulated browsing (pecking?);

4) measure reproductive development, body condition, energy reserves and recruitment of penned grouse on diets with varying levels of monoterpene and protein. (For logistic reasons, this is best accomplished elsewhere than at Saval); and

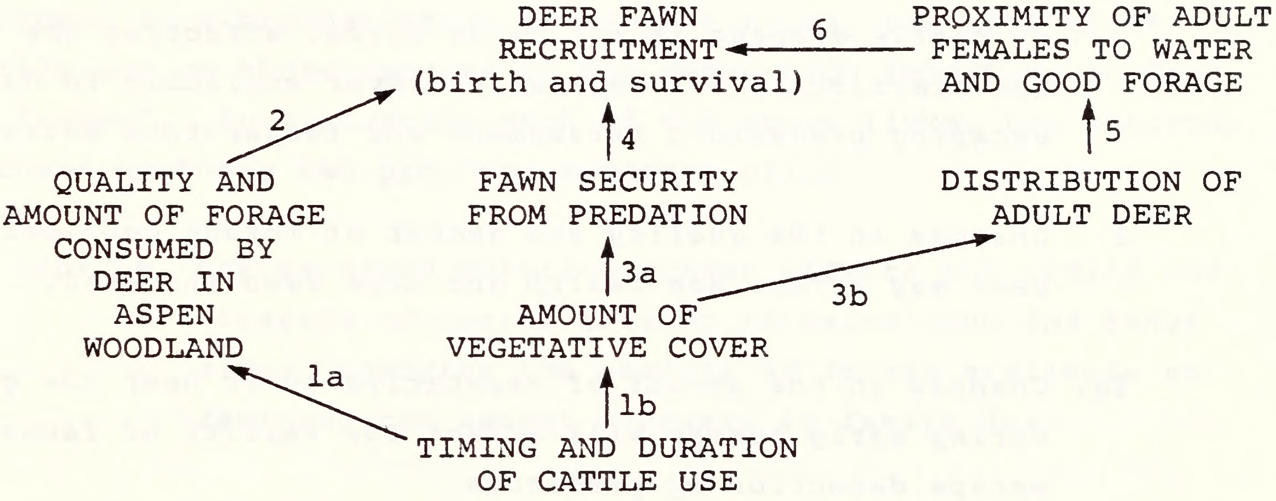
5) track the diet and breeding status of telemetered wild birds for two or more years.

The first two studies are expected to take only one year.

There are no plans to look at the causes of nesting failure, due to both the difficulty of finding nests and the possibility that the researcher's interference may influence the probability of failure. However, it may be possible to compare the frequency of breeding, use of strutting grounds, and physiological states of birds which feed on different sagebrush stands (study 5).

6.9 Effects of Cattle Use of Aspen Woodlands on Deer Fawn Recruitment

Hypothesis 9: *Deer fawn recruitment is affected by the timing and duration of cattle use.*


DEER FAWN RECRUITMENT (birth and survival)
6
PROXIMITY OF ADULT FEMALES TO WATER AND GOOD FORAGE
2
4
5
QUALITY AND AMOUNT OF FORAGE CONSUMED BY DEER IN ASPEN WOODLAND
FAWN SECURITY FROM PREDATION
DISTRIBUTION OF ADULT DEER
3a
3b
AMOUNT OF VEGETATIVE COVER
1a
1b
TIMING AND DURATION OF CATTLE USE

Background Explanation

Timing and duration of cattle use affect fawn survival and recruitment into the herd in two ways:

1) by reducing the quality and quantity of forage consumed by the adult doe, and thus affecting her physiological ability to nourish fawns; and

2) by changing the distribution (in time and space) of vegetative "cover" that both fawn and doe use to survival advantage.

Links

1a. *The deferred rotation scheme affects the timing and duration of cattle grazing in aspen woodland range sites, changing the quality of forage available to deer and the amount consumed by female deer.*

1b. *The deferred rotation scheme affects the timing and duration of cattle grazing in all range sites, affecting the amount and distribution of vegetative cover available to deer for escaping predation, harassment and temperature extremes.*

2. *Changes in the quality and amount of forage consumed by deer may affect doe health and thus fawn survival.*

3a. *Changes in the amount of vegetative cover near the ground during early summer will affect the ability of fawns to escape detection by predators.*

3b. *Changes in the amount of vegetative cover will affect the distribution of adult female deer.*

4. *Fawn security from predation is an important influence on deer fawn recruitment.*

5. *Changes in the distribution of female adult deer (caused by changes in the distribution of vegetative cover) could affect the average distance deer must travel daily to good food and water.*

6. *Fawn survival is affected by changes in the distance adult female deer must travel daily to reach good food and water (because fawns are left longer without protection by the doe).*

Discussion

Two research plans have been submitted to study the effects of the AMP on mule deer populations. The first plan deals mainly with the effects of cattle use of the aspen woodland type on quality and quantity of forage available to female deer; and secondarily with the effects of cattle use in the aspen woodland on understory vegetative cover. The second plan attempts to address, in a broader array of habitat types, the effects of cattle use on those aspects of the vegetation important to deer as "cover". In evaluating each of the above links, the subgroup focused on these two proposed research plans.

Link 1a. *The deferred rotation scheme affects the timing and duration of cattle grazing in aspen woodland range sites, changing the quality of forage available to deer and the amount consumed by female deer.*

The first of the above proposals intends to manipulate the level and timing of cattle utilization within small enclosed pastures and monitor the quantity of vegetation consumed by tame deer within these pastures. Tame deer provide an alternate source of data where observability limits work with wild ones. The work plan has a good experimental design which should allow this link to be evaluated, and produce information relevant to management. Deer diets will be examined monthly.

Link 1b. *The deferred rotation scheme affects the timing and duration of cattle grazing in all range sites, changing the amount and distribution of vegetative cover available to deer for escaping predation, harassment, and temperature extremes.*

A secondary objective of the first research plan is to measure the effect of timing and duration of cattle use on understory vegetation "cover". This will involve measuring how much the vegetation within a few feet of ground level obscures horizontal visibility under various cattle "use" regimes. This kind of "cover" is assumed to be important to fawn survival in that dense cover hides fawns less than one month old from detection by predators. If this assumption is correct, then the proposed work is relevant to management. The potential weakness in the proposed work is in the measure of cover - the investigator must try to measure those cover variables that affect the ability of fawns to escape predation. Given the scarcity of existing information on this topic (Link 3a), the data to be collected may tell little about how cattle use affects fawn survival.

Link 2. *Changes in the quality and amount of forage consumed by deer may affect doe health and thus fawn survival.*

No new experiments on Saval are proposed to address this link. It is unlikely that new work at Saval could add significantly to what has already been done elsewhere relating level of doe nutrition to fawn survival. It is important, however, that existing literature be closely scrutinized to place the first research plan in perspective. The key issue is: does the literature indicate that the expected changes in deer diets are sufficient to affect fawn survival by lowering the health of does?

Link 3a. *Changes in the amount of vegetative cover near the ground during early summer will affect the ability of fawns to escape detection by predators.*

No new experiments on Saval are proposed to address this link because research that provides useful data is unlikely to be feasible. This is unfortuante because this has seldom been addressed by studies elsewhere; it must remain an assumption based on little evidence.

Link 3b. *Changes in the amount of vegetation cover will affect the distribution of adult female deer (because they seek certain types and levels of cover to avoid human harassment, temperature extremes and/or insects).*

The second proposed research plan attempts to clarify the mechanisms operative in this link. Since this work plan was only in the preliminary stages of development prior to the workshop, the subgroup attempted to develop more specific methods for testing various aspects of this link. Several circumstances made this task difficult:

a) the existing literature frequently states that vegetation is important to deer as "cover", but usually fails to demonstrate relationships between deer distribution and characteristics of the cover;

b) because the literature is vague about functional relationships between deer and cover, it is unclear how cover should be measured to determine whether changes in cover will cause changes in deer distribution;

c) if deer densities are low on the Saval Ranch, experimental approaches that try to correlate deer distribution with cover are unlikely to yield quantities of data sufficient for rigorous statistical analysis; and

d) it is unclear whether deer distributional responses to cover variables can be separated from their responses to other variables that may be correlated with cover (e.g. forage quantity and quality).

Sorting out these mechanisms requires pre-experimental investigation of two questions:

1) what are the cover variables to which deer are likely to respond?; and

2) how does the aerial distribution of these variables relate to the aerial distribution of variables such as forage quality and quantity (which may confound the interpretation of data on deer distribution)?.

Due to these uncertainties, it was concluded that a detailed research plan agenda should include the following:

1) a comprehensive review of available literature to determine precisely which measurable aspects of cover are likely to influence deer distribution; and

2) a preliminary field study in late spring-early summer to observe whether deer are distributing themselves in response to these (or other) aspects of vegetative cover.

If, after completion of these initial steps, distributional responses of deer to cover appear real and measurable, then it would be reasonable to develop a detailed research plan based on the preliminary results. It is critical that the study design present specific hypotheses about which cover variables (e.g., shrub canopy cover, horizontal visibility, etc.) affect deer distribution, and devise methods to ensure that the collected data will be amenable to statistical analysis. The responses of deer to cover variables is a difficult ecological problem, and the low densities of deer on the Saval Ranch expand these difficulties.

Link 4. *Fawn security from predation is an important influence on deer-fawn recruitment.*

The subgroup concluded that new research to address this link should not be conducted at Saval. Research at Saval is probably not feasible because of the relatively low density of deer, and, in any case, sufficient evidence is available in the literature to support this link.

Link 5. *Changes in the distribution of female adult deer (caused by changes in the distribution of vegetative cover) could affect the average distance a deer must travel daily to good food and water.*

Research related to Link 3b (above) could provide circumstantial evidence either for or against this link. No research directly related to this link is planned, but might be in the future if preliminary field studies show that deer distribution is strongly affected by vegetative cover.

Link 6. *Fawn survival is affected by changes in the distance adult female deer must travel daily to reach good food and water (because fawns are left longer without protection by the doe).*

No new research is proposed to evaluate the importance of this link. Though logic suggests that this link might be important, there is little relevant information available in the literature.

Conclusions

The following are the subgroup's general conclusions concerning research related to Hypothesis 9:

1) The research plan designed to test the effects of cattle use of aspen woodland on quality and quantity of forage consumed by deer is both relevant and practical. It is likely to produce results useful in management decisions.

2) The work proposed to evaluate the effects of cattle use on hiding cover for fawns is less certain to be relevant. The absence of data showing correlations between vegetative cover and fawn mortality will lessen the utility of the study's results.

3) The proposed preliminary field study will examine habitat selection by deer under different conditions (e.g., with or without fawn) and in different seasons. If the data indicate that deer are selecting for certain variables, then it will be appropriate to ask:

   a) Would these variables be changed significantly by the AMP (at the times when deer are sensitive to them)?;

   b) What alternate hypotheses (i.e., factors other than the measured vegetation cover variables best correlated with deer distribution) could explain the observed patterns of habitat use?; and

   c) How would the AMP affect the mechanisms underlying each of these alternate hypotheses?.

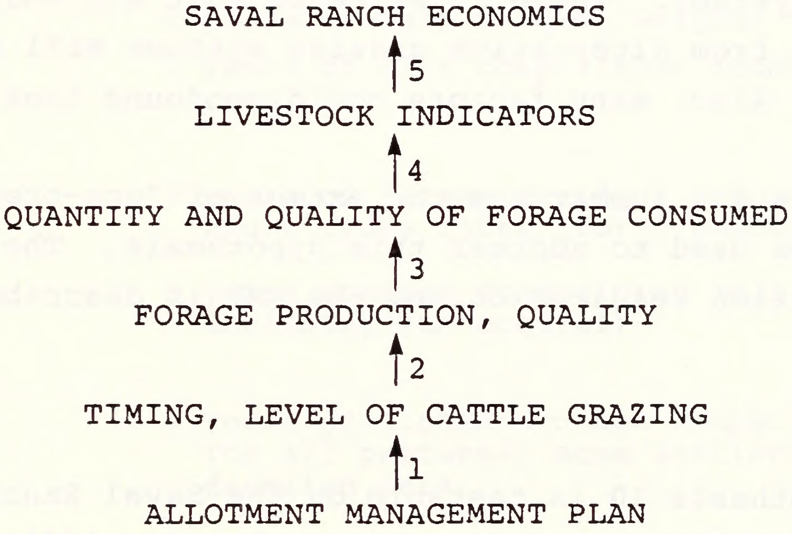
Following the first field season, a simple deer model could be of some use in both integrating existing research and clarifying alternate hypotheses. Using relationships from both the literature and collected data, one could ask such "worst case" questions as:

a) If wild deer respond to cattle utilization in the same manner as tame deer do in the first research study, how sensitive would fawn recruitment need to be to deer diets for the AMP to have an effect on recruitment?; and

b) If deer were to stick rigidly to the patterns of habitat utilization observed in the second research study, how would the AMP change the proximity of adult females to good water and forage?.

6.10 Economic Impacts of the Allotment Management Plan

Hypothesis 10: *The Saval Allotment Management Plan will increase forage production and health in the livestock herd, and improve the economics of the Saval Ranch.*


SAVAL RANCH ECONOMICS
5
LIVESTOCK INDICATORS
4
QUANTITY AND QUALITY OF FORAGE CONSUMED
3
FORAGE PRODUCTION, QUALITY
2
TIMING, LEVEL OF CATTLE GRAZING
1
ALLOTMENT MANAGEMENT PLAN

Links

1. *The Allotment Management Plan (AMP) will affect the timing and level of grazing on the Saval pastures.*

2. *The timing and level of grazing will affect preferred forage production and quality.*

3. *Increases in preferred forage production and quality will increase quantity and quality of forage consumed by livestock.*

4. *The quantity and quality of forage consumed by livestock will improve the health of the livestock herd.*

5. *An improved livestock herd will improve the economic status of the Saval Ranch.*

Discussion

There is good, documented evidence for all linkages. However, link 2 (that the timing and level of grazing affects forage production and quality) is not well documented for sagebrush systems. There is evidence that any change in the forage base from alternative grazing systems will be very slow to develop. Also, many factors could confound link 4 (e.g., disease).

Table 6.1 summarizes the extent of "pre-treatment" data which can be used to address this hypothesis. The extent of data collection required during the AMP is described below.

Conclusion

Hypothesis 10 is testable on the Saval Ranch with continuation of some existing research, plus additional research.

Recommended Research

Ideally this hypothesis would be tested using a "control ranch" on which traditional grazing systems are used. Forage production, forage quality and various livestock indicators would be monitored on both the Saval and the control ranch. Since a control ranch does not exist, the hypothesis must be tested using small scale control pastures.

The subgroup recommended three types of research activities to test this hypothesis:

1) long term monitoring;

2) detailed experiments; and

3) modelling.

Table 6.1: Summary of "pre-treatment" data relevant to hypothesis 10.

COMPONENT	EXTENT OF DATA
livestock	2 years of calf weaning weights 3 years of diet composition from fistulated cows
forage	3 years of forage yield, % crude protein, and % crude fiber (for 5 pastures) 3 years species composition (all pastures including BLM control)
weather	4 years precipitation and temperature data for all pastures; some stations have more detailed data
economics	3 years livestock production costs

Long term monitoring of livestock, forage species composition and cattle diets is essential. Annual livestock measurements should include the actual and adjusting weaning weights, calving interval, conception rate, lactation length and days dry. The composition of forage species and cattle diets should be measured periodically. There is no need to make annual measurements of these variables because species composition is insensitive to short term climatic variability, and is expected to change slowly under the AMP. Data on the blood composition of cattle (monitored when they are being moved from each pasture) can apparently be related to major changes in the forage base.

A detailed experiment should be conducted to test the following hypothesis:

Use of the AMP on the native BLM and Darling pastures will improve the nutritional status of cattle and forage production and quality, relative to traditional grazing systems on two control pastures.

Cattle blood composition, forage yield and forage quality would be monitored on the control, BLM native and Darling pastures.*

There are three modelling activities relevant to hypothesis 10:

1) continued improvement of Allen Torell's economic model, which directly addresses link 5;

2) development of empirical models for predicting cattle weight gain as a function of blood composition variables; and

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* These data could possibly be compared with those from animals relying on winter range (e.g., Lincoln County cattle).

3) use of SPUR or other models to account for climatic variability in forage production.

7.0 CONCLUSIONS

The preceding review of riparian research produced many detailed recommendations. These details should not obscure the workshop's major conclusions, which are as follows:

1) Since differences between the AMP and traditional grazing systems are likely to be subtle, there is a need to examine the variability in existing data in order to optimize experimental designs and future results.

2) A thorough review of relevant published and unpublished work is an essential prerequisite to the development of new research or monitoring plans.

3) The terms "research" and "monitoring" have different meanings to different people. The objectives of each work activity must therefore be explicitly defined in terms of either:

    a) the hypothesis that is being tested; or (if a hypothesis is not being tested),

    b) the group(s) for whom data is being collected and how they will use such data.

4) There is need for a control pasture(s) on U.S. Forest Service lands.

5) Work on control pastures must be carefully coordinated and managed.

6) The beaver research proposal (Section 6.2) would have very beneficial spinoffs for other research questions.

Each of these conclusions are discussed below.

Measurement of Variability

Most of the data collected during the first three years of the Saval Project are described as baseline information. Beanlands and Duinker (1983) define the term "baseline" to mean:

> "a description against which subsequent changes can be detected through monitoring (after Hirsch (1980)). To fulfill this role, baselines normally must consist of statistically adequate descriptions of the variability inherent in the valued ecosystem components prior to the onset of the planned action."

In order to assess whether current baseline descriptions are statistically adequate, it is necessary to do three steps:

1) select the statistical test which will be used to assess whether or not an ecological component has significantly changed as a result of one or more actions;

2) estimate the average and maximum amount of change that is expected to occur in the parameter of interest; and

3) apply the statistical test selected in (1) to the existing and "expected" data to assess whether or not the effect will be statistically detectable. For most parameters, it will probably be necessary to assume that management actions change only the mean, and not the variance. Appendix A contains a useful example of statistical analysis to optimize sampling design.

Step 2 can be performed using the researcher's best judgement, examples from the literature, or a simulation model. The riparian model described in this report and existing hydrological models (listed in Section 6.2) could serve this purpose.

Following the procedure outlined above will avoid pursuing hypotheses for which testing is not feasible and maximize the efficiency of experimental designs for testable hypotheses.

Review of Work Done Elsewhere

Too often, it is assumed that every situation is unique. If that was the case, there would be little purpose in performing scientific research, since it would be impossible to draw general conclusions. It is a regrettably common syndrome for scientists to reject existing studies as being irrelevant to their particular problem, and simultaneously maintain that the results of their research will be of universal interest and application. Though this syndrome was not apparent among Saval Project scientists, it is a fact of scientific research that is worth recognizing, and avoiding.

On many occasions during the workshop, subgroup participants stated that they were unaware of any previous quantitative studies dealing with the hypothesis of interest. This may mean:

1) quantitative studies have never been done before;

2) quantitative studies have been successfully performed, but were not known to the participant;

3) quantitative studies have been attempted, but due to difficulties in testing the hypothesis, failed, and were either never published or appeared as qualitative studies; or

4) quantitative studies are currently underway.

There is much that can be learned from possibilities 2 to 4 (e.g., why did the quantitative study fail?). Before making major changes or additions to current research programs, it is critical that relevant work conducted elsewhere be reviewed thoroughly. This should involve personal contact with all leading researchers, not only an examination of published literature.

Research vs. Monitoring

The Memorandum of Understanding (MOU) for the Saval Project (signed by BLM, ARS, USFS, SCS, UNR and the Saval Ranch) operationally defines "research" and "monitoring" in terms of the actions performed. Among other responsibilities, the signatories are directed to:

> "Monitor the status of basic physical phenomena, resources and resource uses on the Saval area to guide sound rangeland management on the area and to detect significant changes in the physical, biological and cultural features of the area."; and
>
> "Design, establish and accomplish integrated research to explain the relationships between specific management actions and specific changes in the resources of the area and their uses, and to extrapolate these findings to other comparable areas."

It is worthwhile to contrast the MOU's description of the purposes of monitoring with those proposed by Beanlands and Duinker (1983):

> "In the specific context of ecological investigations within impact assessment....monitoring refers to repetitive measurement of specific ecological

> phenomena to document change primarily for the purposes of (i) testing impact hypotheses and predictions and (ii) testing mitigative measures."

Beanland and Duinker's definition compels monitoring activities to test something, either an impact hypothesis or a mitigative measure. The MOU allows monitoring activities which "guide sound rangeland management" but do not necessarily test anything, whereas research activities must "explain relationships" (i.e., test hypotheses).

The reason for highlighting these two very different definitions of monitoring is to illustrate that monitoring and research overlap, and that this overlap is healthy. Monitoring can help to "explain relationships" and research can "guide sound rangeland management", even though these benefits may not be their primary intent. In reviewing each monitoring activity, it is worthwhile to ask:

a) Will the data be used to test impact hypotheses, predictions or mitigative measures?; and

b) If no, is it feasible to change the monitoring program so that the data produced could be so used?.

If the answer to both questions is "no", then the only "acceptable" function of the monitoring activity can be to guide rangeland management by providing descriptive information. It then behooves the party proposing the work to demonstrate that range managers will, in fact, be guided by the collected data. If not, the monitoring activity serves neither of the two purposes outlined in the MOU.

Similarly, in examining each research activity, it is important to ask:

a) Will the results of this research help to improve rangeland management, both on the Saval and elsewhere?; and

b) If no, could the research design be altered or expanded so that the results could have such benefits?.

By intensively examining the possibilities for integrating research and monitoring activities (beyond the original definitions of these terms), the Saval project can maximize the value of the work performed.

USFS Control Pasture

It was agreed at the workshop that it would be very useful to have one pasture which received a fixed and repeated treatment against which all the other pastures could be compared. Three options were discussed:

1) A control pasture, comparable to that on BLM native, that maintains the "traditional" season-long grazing from July 1 to September 30 with no deferment.

2) An experimental pasture that simulates on a small scale a three-pasture deferred rotation system (instead of the two-pasture system in effect since 1970). The rationale is that the three-pasture system was considered biologically preferable for the AMP but was rejected because of the huge expense in refencing the entire FS allotment. This would simulate the costs/benefits for riparian zone on a smaller scale.

3) A back to back combination of control and experimental pastures.

The first alternative was generally favored as higher priority. It was pointed out that a control pasture would have to be several square miles in size, and that control animals would need to be from the core herd to properly evaluate long term effects. Fencing, which costs approximately $3,000.00/ mile on flat land, would be a major expense. There is an obvious need for a complete analysis of the costs and benefits of establishing a control pasture on USFS lands.

Coordination of Control Pastures

The control pastures offer an opportunity to rigorously test impact hypotheses. For this opportunity to be realized, it is essential that the controls be maintained for the duration of the Saval Project. This requires close coordination between researchers and the ranch managers. The project scientists should be able to demonstrate that maintenance of the controls is in the best long term interests of the ranch (i.e., more valuable information from which to make management decisions).

Close coordination is also necessary to avoid duplication of research efforts, incompatible research designs, and confounding of hypothesis tests. Confounding of hypothesis tests is a major concern in the Saval Project. As Laycock (1983) points out:

> "Management (fencing, water development undesirable plant control, and factors influencing animal distribution) taken as a whole may be the key to success or failure of any particular grazing system and the grazing controls (timing and intensity of grazing) may have little additional effect."

Beaver Research Proposal

This proposal represents a new direction for the Saval Project, but one which offers great potential for accomplishing valuable interdisciplinary research in the riparian zone. If logistical difficulties prevent implementation of the complete study plan outlined in Section 6.2, there are still possibilities for valuable, smaller scale tests of many of the hypothesized linkages.

8.0 MODEL RESULTS

The conceptual riparian model described in Chapters 2 to 5 of this report has been translated into a computer simulation model which can be used on an Apple microcomputer. A number of refinements to the conceptual model had to be made during the translation to improve model execution speed, make the structure of the computer code more logical, or remove some problems with the original formulation of some of the functional relationships.

Once the simulation model was constructed and debugged, it was parameterized for the Gance Creek watershed. The generic spatial units of Figure 2.1 were assigned the following Saval Ranch pastures:

a) mountainous - south Forest Service pasture;

b) alluvial - Upper Mahala and control pastures; and

c) hay meadow - Saval and "jungle" pastures.

Saval Ranch researchers provided areas of riparian and non-riparian land in each pasture, forage production estimates for riparian forage, and stream channel measurements to initialize the model.

This chapter has two major sections. The first section describes the changes that were made to the conceptual model described in Chapters 2 to 5 of this report when it was translated into a simulation model. The second section presents simulation results from the riparian model for a number of different scenarios.

8.1 Modifications to the Riparian Model

8.1.1 Model Bounds and Structure

Originally, the model was to have explicitly considered the dynamics of the riparian zone only. However, many of the cattle indicators, such as fall wean weights and the economic revenue from fall cattle sales, depend very heavily on the level of forage consumption from non-riparian areas. Also, the distribution of cattle foraging between riparian and non-riparian zones will influence the level of cattle use of the riparian zone. Therefore, the spatial extent of the model was expanded so that each of the three spatial units is now divided into riparian and non-riparian zones. This distinction is only used in the model in the calculations of livestock foraging and cattle months in the riparian zone; it is not used in calculations of hydrology, fisheries or wildlife indicators.

The original method of modelling the interaction between vegetation and cattle was to run the vegetation model for an entire year without cattle grazing, have cattle graze on the forage with assumptions about natural forage mortality during the year, and finally update the entire year's vegetation dynamics given expected dynamics without grazing plus actual grazing levels (Figures 3.2 and 5.2). This method was modified so that vegetation/cattle interactions occur within the year. In each time step (2 weeks long), forage biomass is updated by first removing forage consumed by cattle in the previous time step, then using current biophysical factors to compute new forage levels. These new forage levels are then made available to cattle. This method of conceptualization more closely mimics the dynamics of the real system.

8.1.2 Vegetation/Wildlife Submodel

There are three major changes to the vegetation/wildlife submodel:

a) interaction between forage types (Equation (3.1));

b) calculation of plant vigor; and

c) hay production.

In the original model conceptualization, the maximum total forage biomass was constrained to be less than 5,000 lbs./acre; the biomass of each forage type was reduced proportionately if the total biomass exceeded this figure (Section 3.2). Under these conditions, slow growing forage types (e.g., shrubs) or those which tend to have low biomass (e.g., legumes) always went rapidly extinct and the system tended to simplify to one to three forage types exclusively. In the present model, there are no interactions between forage types. Each forage type has a maximum biomass which it can achieve; this maximum biomass was set to twice the 1980 forage production figures provided to us. Both conceptualizations are far removed from the real dynamics of the system. However, only the latter conceptualization ensures that all forage types remain in the system.

The original relationship between plant vigor and cattle grazing distinguished between grazing before the period of flowing and grazing afterwards (Equation (3.6)). This distinction was removed, because there was insufficient understanding of how grazing and production during different periods of the growing season influence plant vigor in the following season. Equation (3.6) is now:

$$UT_{i,j} = \left[CB_{(i,j)} / PB_{(i,j)}\right] * 100 \qquad (8.1)$$

where,

$CB_{(i,j)}$ = total biomass of vegetation type i in spatial unit j consumed by cattle; and

$PB_{(i,j)}$ = total plant production.

Finally, the dynamics of hay production have been more accurately defined. Shrub biomass is not included in the hay production calculations (Equation (3.7)) and only the riparian zone is harvested for hay in the first week of August.

8.1.3 Hydrology/Fisheries Submodel

The only major change to the hydrology/fisheries submodel is the time of year the fisheries model uses riparian shrub cover to calculate fish survival. If cattle are grazing in the riparian zone, the shrub cover at the end of the last time step in which the cattle are on the riparian zone is used. If cattle are not grazing in the riparian zone (with the hay meadow pasture or the alluvial pasture every third year), the shrub cover on October 31 is used.

8.1.4 Cattle/Economics Submodel

Three major areas of the cattle/economics submodel have been modified:

a) calculation of forage consumption (Equation (5.2));

b) calculation of riparian zone use (Section 5.5); and

c) calculation of hay needed to maintain cattle over the winter.

Under the original conceptualization of forage consumption, cattle were assumed to be able to consume up to 95% of the forage biomass (Equation (5.3)). In reality, a much smaller portion of total forage biomass is available to cattle. For example, much of the shrub biomass is woody and cannot be consumed by livestock. In the present model, 100% of legume and desirable forb and grass biomass, 10% of shrub biomass, 50% of sedge and rush biomass, and

30% of undesirable forb and grass biomass can be consumed by cattle.

The original conceptualization of riparian use by cattle did not take into account the time spent by cattle feeding off the riparian zone. The present model accounts for the influence of the distribution of cattle feeding on riparian zone use. It is assumed that, even under conditions which would cause cattle to feed exclusively in non-riparian areas (e.g., when they have depleted riparian forage), cattle would spend 16 hours per day (67% of a day) resting in the shade and near the water sources of the riparian zone. Therefore, the number of cattle months spent in a riparian zone is now calculated by:

$$CD = CU * 0.5 * YC * \left[(1 - DF) + DF * \frac{DC}{TC}\right] \tag{8.2}$$

where,

CD = cattle months;

YC = total number of cattle;

0.5 = months per time step (2 weeks = ½ month);

DF = fraction of day spent by cattle feeding (as opposed to resting) in the riparian zone (0.33);

DC = forage consumption on the riparian zone;

CU = cattle use factor (as in Equation (5.9)); and

TC = total forage consumption.

The cattle/economics subgroup originally did not have sufficient time to construct functional relationships for determining the amount of hay the ranch would have to buy to maintain the cattle herd over the winter. The functional relationships in the original Saval integrated model representing hay purchases (Sonntag, et al., 1981; Section 5.6) have been included in the riparian model.

8.2 Model Scenarios

A total of six model scenarios are presented in this section. Two scenarios present riparian zone dynamics within a single year; the remaining four scenarios examine changes in the riparian zone over a 12 year period. Temperature and precipitation patterns vary randomly in all scenarios but all scenarios have the same sequence of random variation.

The two single year scenarios are:

a) Scenario 1 - no cattle grazing; and

b) Scenario 2 - cattle grazing pattern according to the first year of the Allotment Management Plan.

The four 12-year scenarios are:

a) Scenario 3 - no cattle grazing;

b) Scenario 4 - historical cattle grazing pattern. In this scenario, 50% of the cattle graze on the alluvial spatial unit for the month of June and on the mountain spatial unit for the months of July, August, and September every year. The reduced number of cattle is to reflect the fact that the pastures with which the alluvial and mountain spatial units are being rotated would be open to cattle in this period as well, thereby distributing the grazing pressure over a larger area.

c) Scenario 5 - cattle grazing pattern according to the Allotment Management Plan; and

d) Scenario 6 - Allotment Management Plan cattle grazing pattern with addition of water sources in non-riparian zones. This is intended to examine the hydrological, fisheries, and wildlife effects of reducing grazing pressure in the riparian zone. This was simulated in the model by allowing the cattle to consume only 50%, rather than 95%, of the riparian zone forage before moving to non-riparian areas. Cattle move to the non-riparian zone to search for forage once 50% of the riparian forage has been removed.

When examining scenario results, it is important to keep in mind that the quantitative values of the indicators are of less importance than the qualitative differences in model prediction under alternate management regimes. The model does a poor job of predicting realistic forage production values; however, predictions of long term trends in riparian forage production and hydrology indicators under different grazing strategies are believable and can be reasonably explained in terms of important ecological processes contained in the model.

8.2.1 Single Year Scenarios

Simulation results from the single year scenarios are presented in Figures 8.1 to 8.6. The time axes on these figures represent 2 week time intervals from April 1 to October 15. The final time step on the graphs represents the five month time step from November 1 to March 31.

Weather Dynamics

Within-year trends of maximum temperatures during each two week period (Figure 8.1a) show a gradual warming through the first half of the year and a cooling during the late summer and fall.

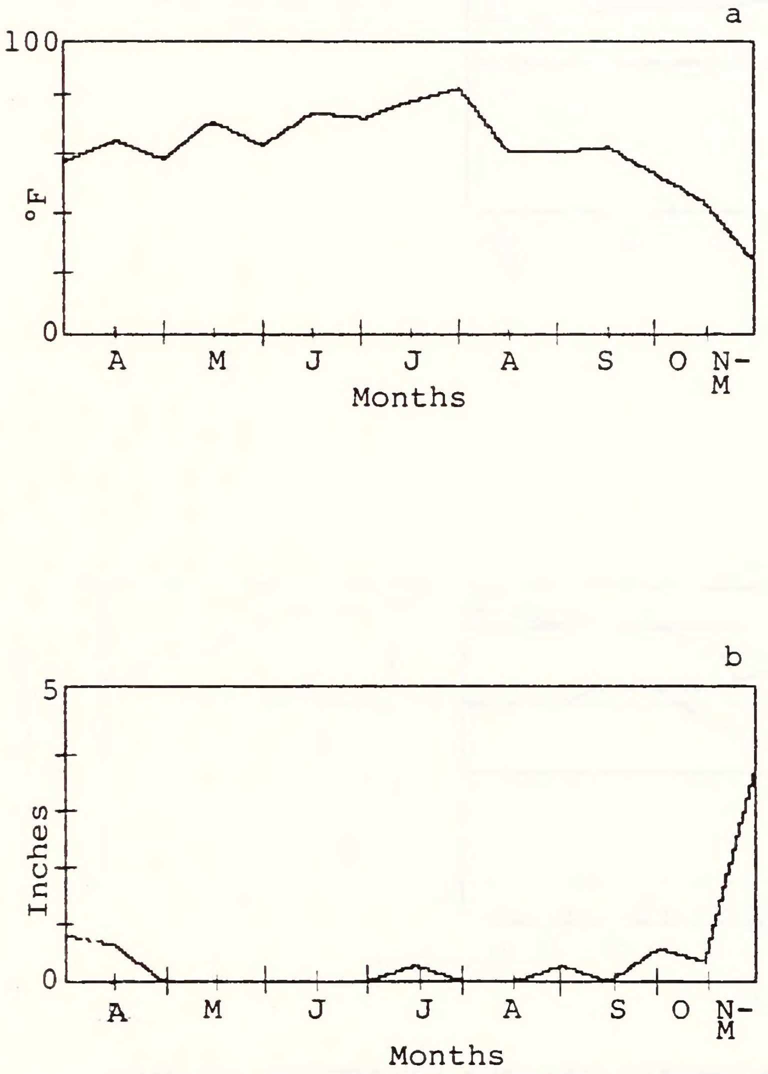


Figure 8.1: Simulated average maximum daily temperature (a) and biweekly accumulated precipitation (b). Both temperatures and precipitation vary from year to year, but within each year the same values are applied to each spatial unit.

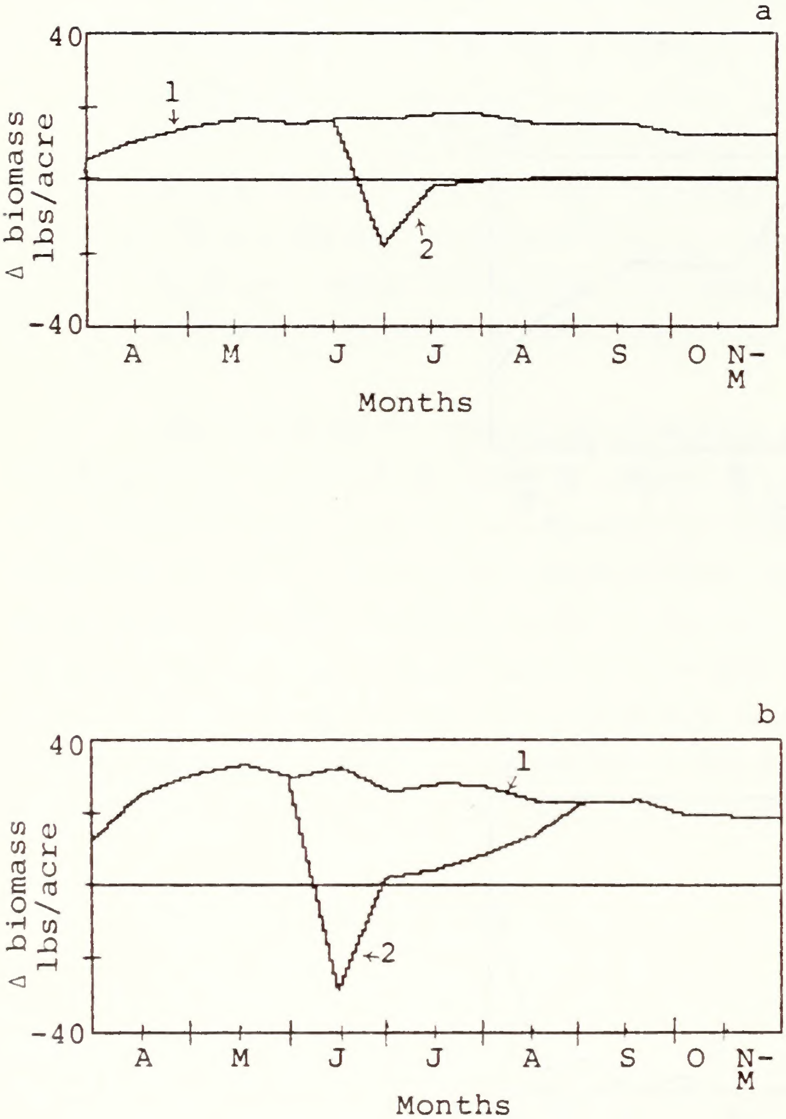
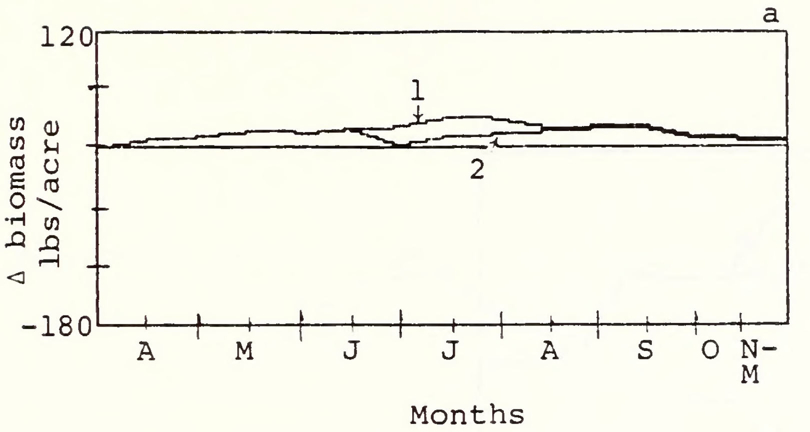


Figure 8.2: Simulated biweekly changes in forage biomass of legumes in (a) mountainous (south Forest Service) and (b) alluvial (Upper Mahala) riparian zones under two scenarios: 1 = no cattle grazing; 2 = grazing according to year 1 of AMP.



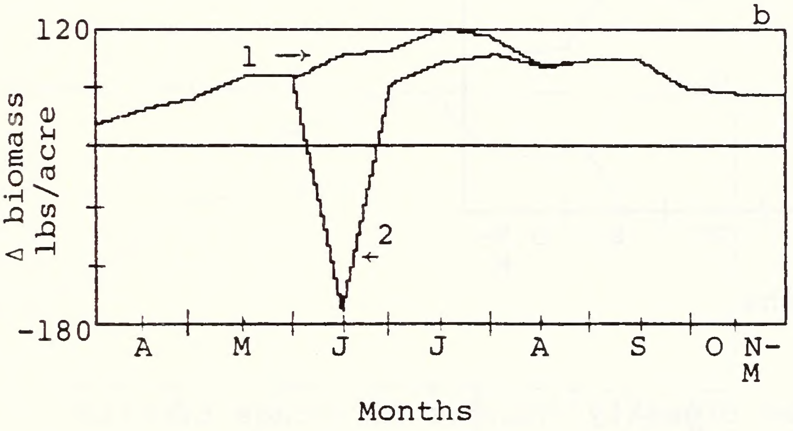
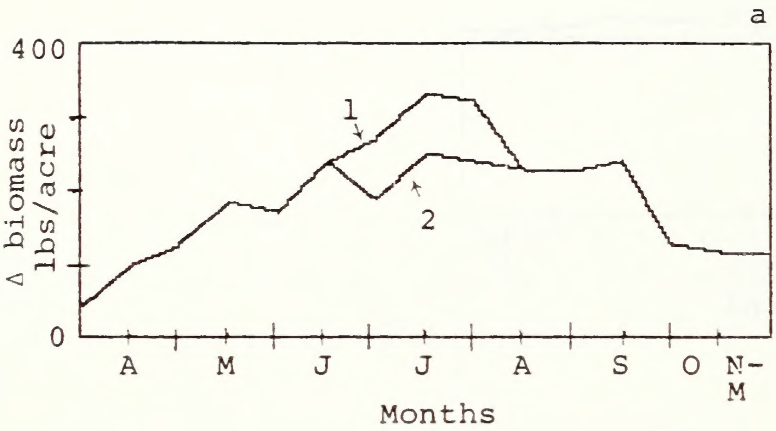


Figure 8.3: Simulated biweekly changes in forage biomass of sedges and rushes in (a) mountainous (south Forest Service) and (b) alluvial (Upper Mahala) riparian zones under two scenarios: 1 = no cattle grazing; 2 = grazing according to year 1 of AMP.



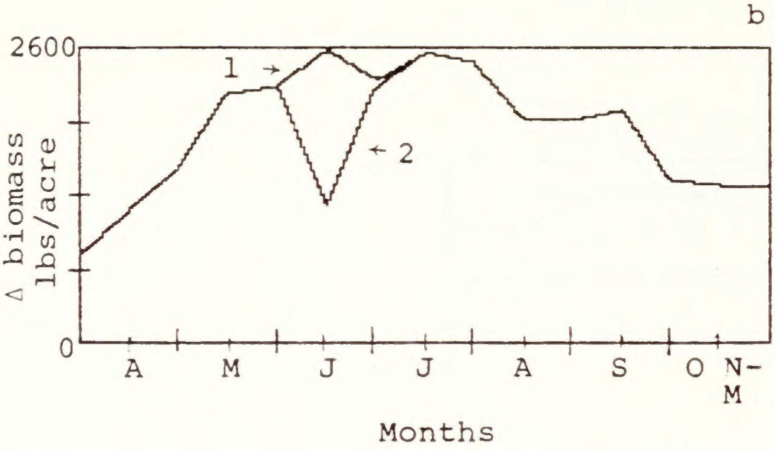
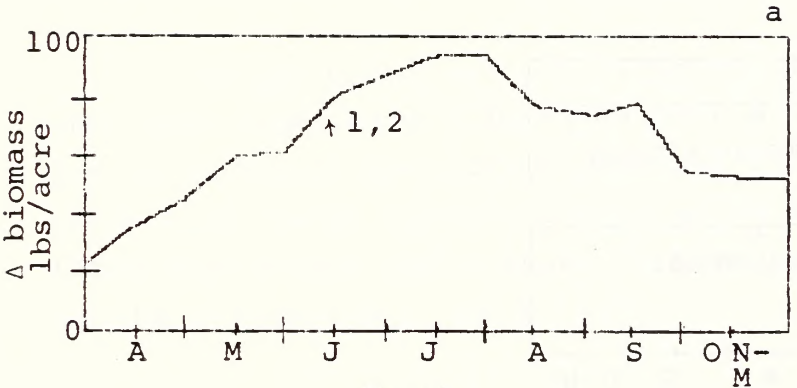


Figure 8.4: Simulated biweekly changes in forage biomass of grasses and forbs in (a) mountainous (south Forest Service) and (b) alluvial (Upper Mahala) riparian zones under two scenarios: 1 = no cattle grazing; 2 = grazing according to year 1 of AMP.



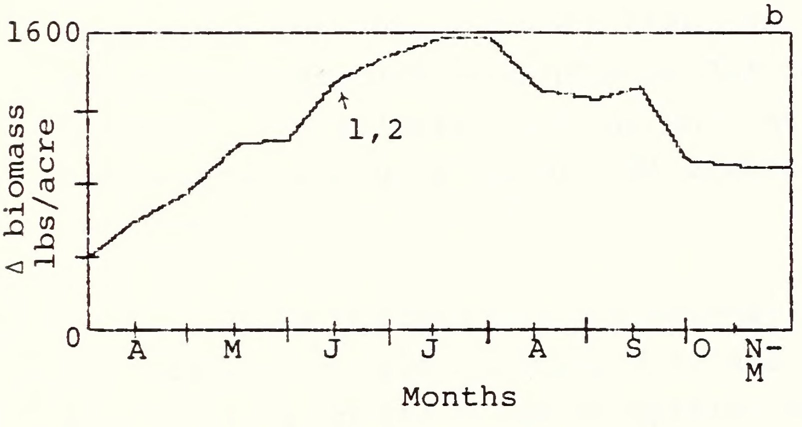


Figure 8.5: Simulated biweekly changes in forage biomass of shrubs in (a) mountainous (south Forest Service) and (b) alluvial (Upper Mahala) riparian zones under two scenarios: 1 = no cattle grazing; 2 = grazing according to year 1 of AMP.

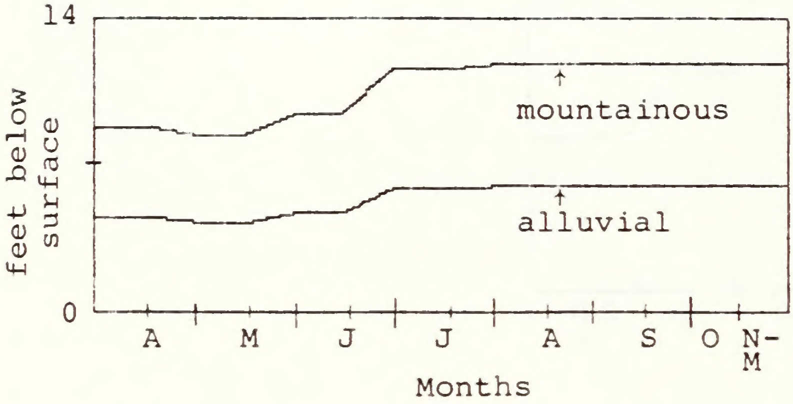


Figure 8.6: Simulated biweekly water table depths in mountainous (south Forest Service) and alluvial (Upper Mahala) riparian zones.

Precipitation (Figure 8.1b) is sporadic throughout the year and the total annual precipitation is about 8 inches. The large peak in precipitation during the final time step represents total precipitation from November 1 to March 31.

Vegetation Dynamics

Forage trends in the riparian zone (Figures 8.2 to 8.5) show that temperature dynamics have a large influence on vegetation, particularly in the late summer and fall. Declining forage production rates in this period occur because of declining temperatures and not changes in precipitation or water table depths (Figures 8.1 and 8.6).

Forage production for all vegetation types is higher in the alluvial spatial unit (Upper Mahala) than in the mountainous (south Forest Service) spatial unit. This occurs because the water table is fewer feet below the surface in the alluvial spatial unit than in the mountainous spatial unit (Figure 8.6). The higher water table in the alluvial spatial unit, ranging from about 4 to 5 feet below the surface, is closer to the optimal conditions for forage growth than the 9 to 11 feet in the mountainous spatial unit (Figure 3.4 shows optimal water table depths). The alluvial spatial unit has a higher water table than the mountainous unit because of greater channel widths (see Equation (4.5)).

Cattle grazing has the severest effects on legumes, sedges and rushes, the most preferred forage types (Figures 8.2 and 8.3), particularly in the alluvial spatial unit. Forage consumption of forage types declines with decreasing forage preference, so that grass and forb consumption is only moderately influenced by grazing (Figure 8.4), and shrub production is not influenced at all (Figure 8.5). The effect of cattle grazing is more pronounced on the alluvial spatial unit than the mountainous spatial unit in spite of the fact that the alluvial spatial unit has a much higher production of forage. This is because the area of the alluvial riparian zone is only about 7% of the area of the mountainous riparian zone, so that the total available biomass of preferred forage is lower in the alluvial zone. Cattle forage demand is approximately the same in both spatial units. Therefore, the forage consumption will be proportionately higher on the alluvial riparian zone than on the mountainous riparian zone.

Forage biomass, in most cases, recovers very quickly after cattle grazing (Figures 8.3b, 8.4 and 8.5). This indicates that the functional relationship describing plant growth rate (Equation (3.3)) may be providing too rapid plant growth. The alternate plant growth rate relationship (Equation (3.2)) would provide for too slow a growth rate. An important model refinement would be to derive a realistic functional relationship for forage growth rate from time step to time step.

8.2.2 12-Year Scenarios

The results of the 12-year scenarios are presented in Figures 8.7 to 8.13. The model saves the value of each indicator at a particular time step during the year; vegetation and wildlife indicators were saved on August 1 of each year, and the hydrology, fisheries, cattle and economic indicators were saved on October 31 of each year.

Vegetation Dynamics

In multi-year scenarios, the cumulative forage production from April 1 to August 1 is calculated and saved for graphical display. Vegetation dynamics are presented in Figures 8.7 to 8.10.

The pattern of preferred plant types being more heavily affected by cattle grazing, observed in the single year scenarios, is also apparent in the 12-year scenarios. Forb, grass, and shrub biomass change very little or not at all from no grazing conditions when various types of grazing regimes are applied (Figures 8.9 and 8.10). However, legume, sedge, and rush biomass are markedly

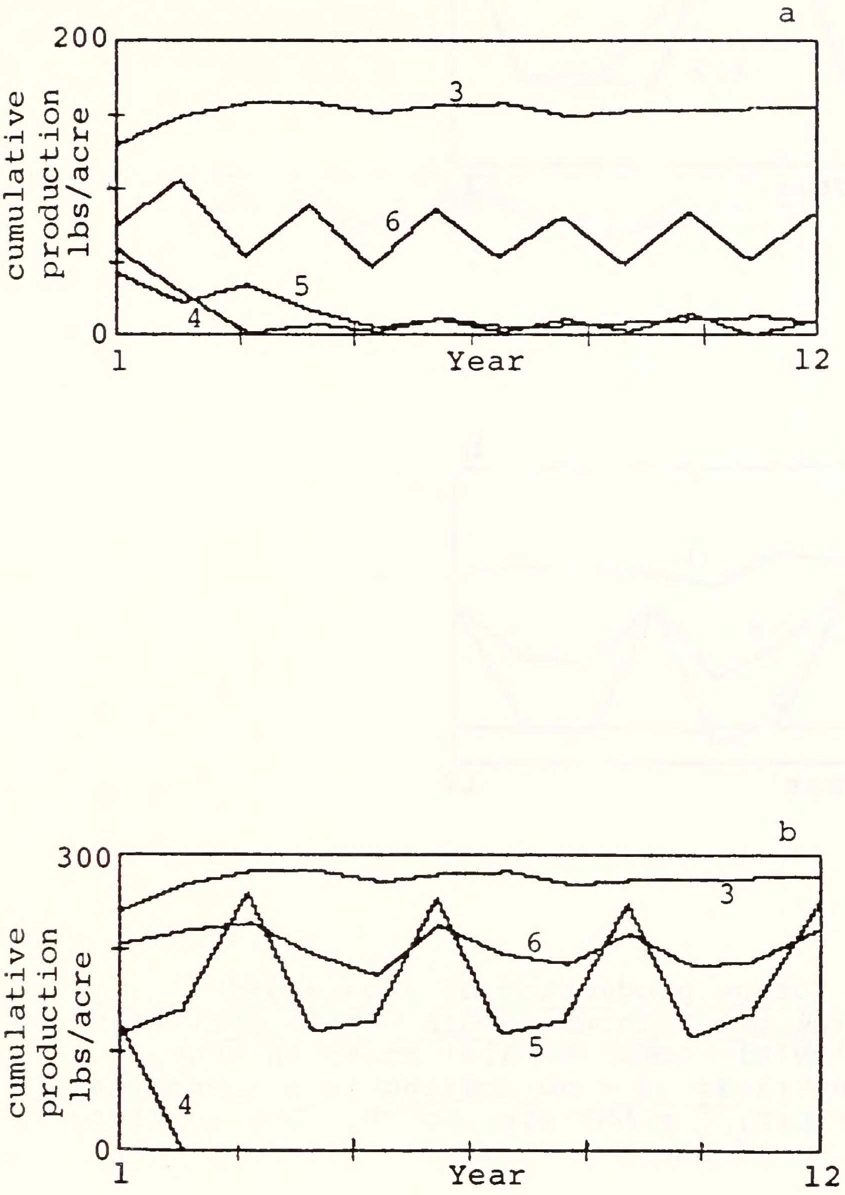


Figure 8.7: Cumulative forage production of legumes in (a) mountainous (south Forest Service) and (b) alluvial (Upper Mahala) riparian zones under 4 scenarios: 3 = no grazing; 4 = historical grazing pattern; 5 = AMP grazing; 6 = AMP grazing plus addition of water sources.

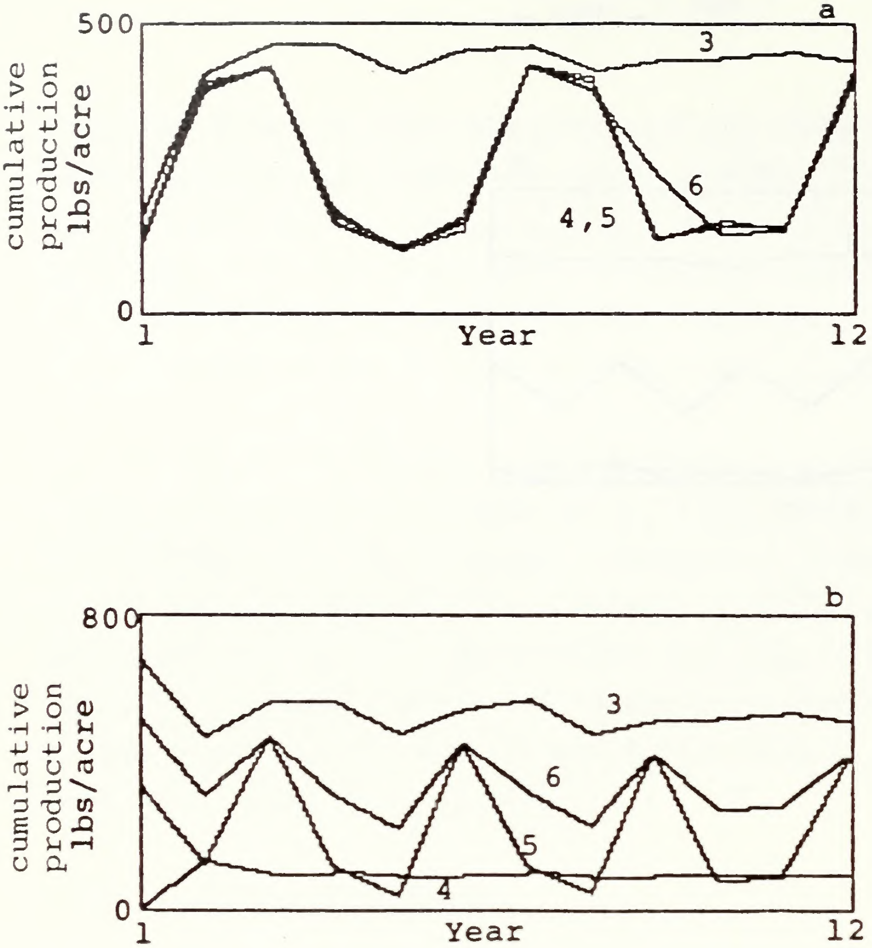
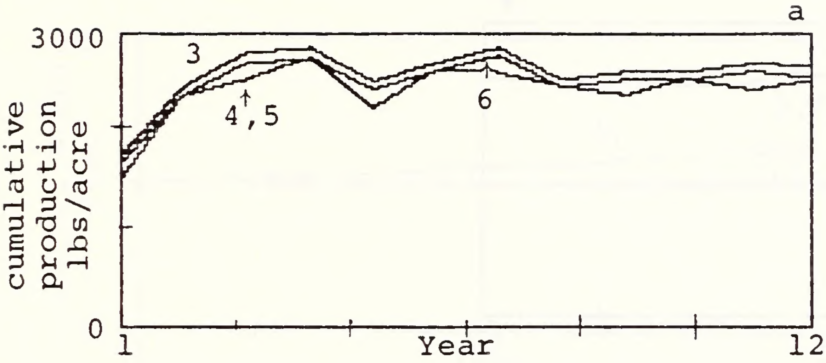


Figure 8.8: Cumulative forage production of sedges and rushes in (a) mountainous (south Forest Service) and (b) alluvial (Upper Mahala) riparian zones under 4 scenarios: 3 = no grazing; 4 = historical grazing pattern; 5 = AMP grazing; 6 = AMP grazing plus addition of water sources.



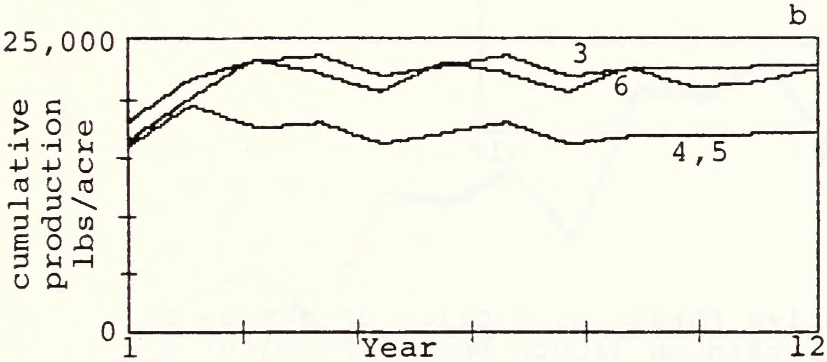


Figure 8.9: Cumulative forage production of grasses and forbs in (a) mountainous (south Forest Service) and (b) alluvial (Upper Mahala) riparian zones under 4 scenarios: 3 = no grazing; 4 = historical grazing pattern; 5 = AMP grazing; 6 = AMP grazing plus addition of water sources.

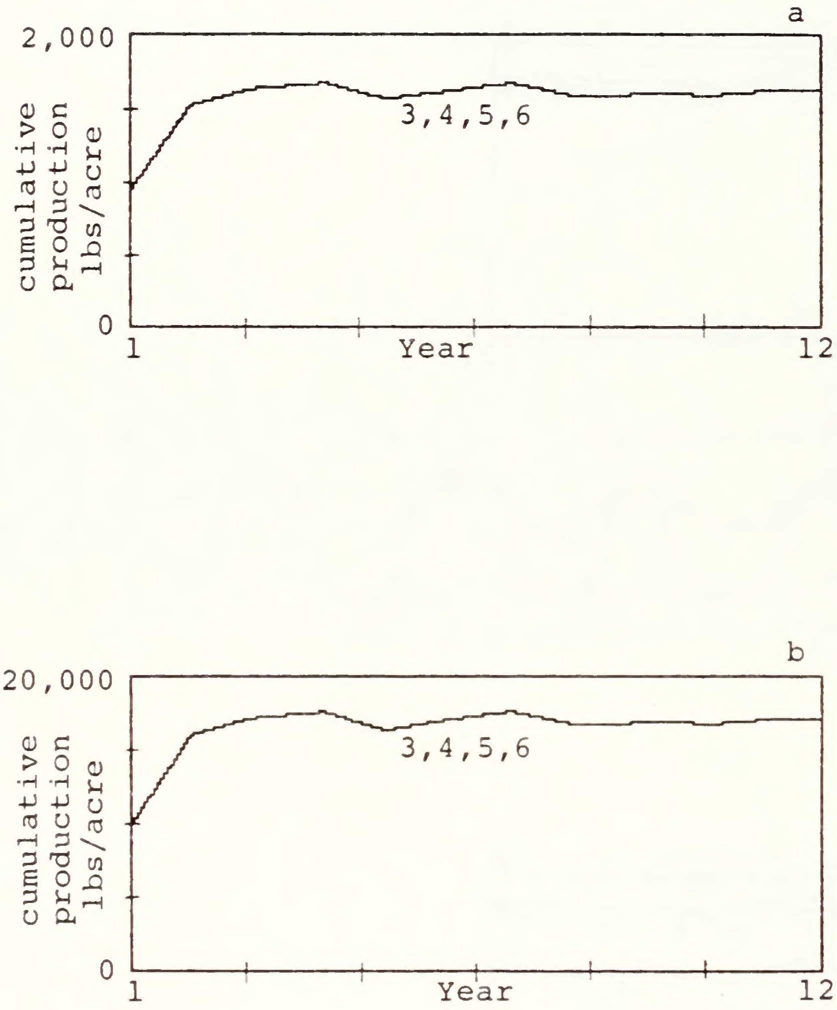


Figure 8.10: Cumulative forage production of shrubs in (a) mountainous (south Forest Service) and (b) alluvial (Upper Mahala) riparian zones under 4 scenarios: 3 = no grazing; 4 = historical grazing pattern; 5 = AMP grazing; 6 = AMP grazing plus addition of water sources.

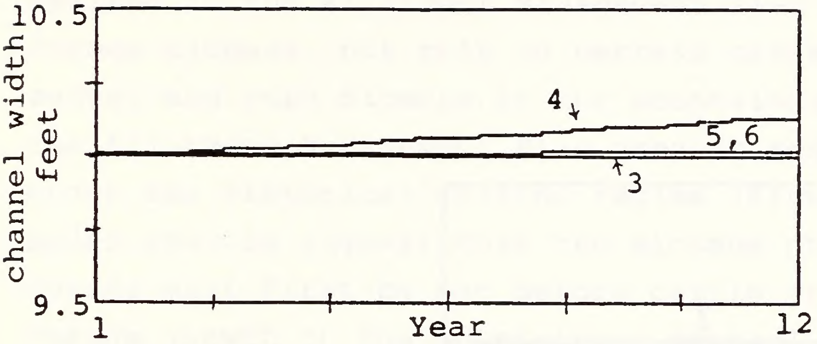


Figure 8.11: Simulated channel widths in the alluvial spatial unit under 4 scenarios: 3 = no grazing; 4 = historial grazing pattern; 5 = AMP grazing; 6 = AMP grazing plus addition of water sources.

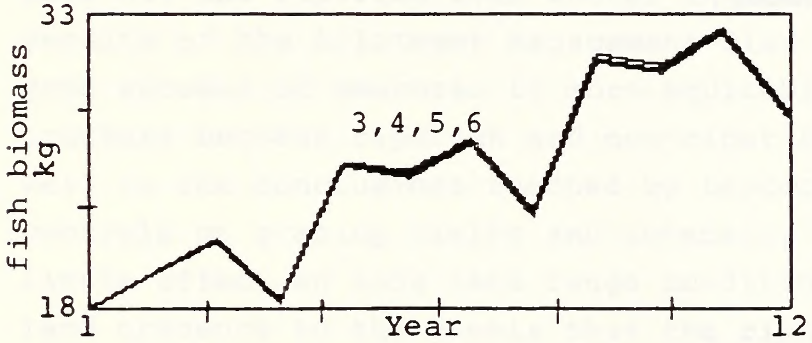


Figure 8.12: Simulated total fish biomass under 4 scenarios.

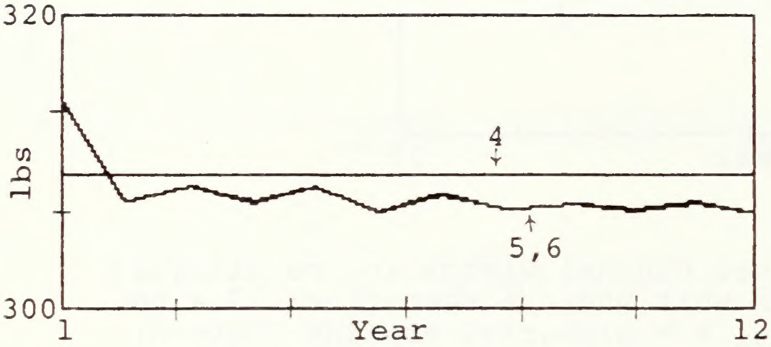


Figure 8.13: Mean cattle weights under the three grazing scenarios: 4 = historical grazing pattern; 5 = AMP grazing; 6 = AMP grazing plus addition of water sources.

different from no grazing conditions whenever any grazing regime is implemented (Figures 8.7 and 8.8).

The results also show that, in general, the grazing regime defined in the Allotment Management Plan can increase long term forage biomass, but only in certain cases. For example, legume, sedge, and rush biomass in the mountainous spatial unit under the Allotment Management Plan grazing regime fare no better than under the historical grazing regime (Figures 8.7a and 8.8a). The model results suggest that the minimum physiological needs of forage must first be met before cattle grazing can be allowed. Forage growth on the mountainous spatial unit is severely limited because of a low water table (Figures 8.2 to 8.5). Forage with poor growth is not able to withstand intense grazing pressure, while forage with good growth rates can withstand heavy grazing pressure (Figures 8.7b and 8.8b).

The model also suggests that tactics to move cattle away from the riparian zone can greatly improve the long term condition of riparian zones. Figures 8.7 and 8.8b show that long term legume, sedge and rush biomass is greatly increased when cattle move off the riparian zone sooner in search of forage. The mixed results of the Allotment Management Plan grazing regime, plus the good success of measures to more equitably distribute grazing pressure between riparian and non-riparian zones, correspond very well to the conclusions reached by Laycock (1983). He found that controls on grazing timing and intensity by themselves may have little effect on long term range condition. The model results lend credence to the thesis that the riparian zone will not benefit from an alternate grazing regime alone, but that additional management activities need to be taken to shift the distribution of grazing toward non-riparian areas.

Hydrology and Fisheries Dynamics

Although the forage benefits from the Allotment Management Plan grazing regime may be mixed, the benefits to stream bank erosion are not (Figure 8.11). Channel width in the alluvial spatial unit increases steadily from cattle use under the historical grazing regime, while increases under the Allotment Management Plan grazing regime are much slower and less pronounced.

Fisheries biomass is influenced very little by alternate grazing systems (Figure 8.12). The two major links between vegetation and fisheries are through bank vegetative cover and channel width effects on flow depth. Grasses, forbs, and shrubs, the forage types which contribute most to total vegetative biomass (Figures 8.3 to 8.5, 8.7 to 8.10), and therefore to bank vegetative cover (Figure 3.9), have low grazing preference. Since their biomass changes very little under the various grazing regimes, the vegetation cover therefore also changes very little. The insensitivity of cover to grazing means that fish populations will be insensitive to grazing as well. Changes in bank channel widths (Figure 8.11) are insufficient to affect fish biomass via changes in flow depth and fish survival (Equation (4.5); Figure 4.4b). The main source of variation in fish biomass is the year-to-year variation in precipitation, which does alter flow depth sufficiently to affect fish survival.

Figure 8.13 shows the trends in cattle weights under the three alternate grazing regimes. Cattle weights are highest under the historical grazing pattern. This is because in the model the cattle have twice as much area to graze under the historical pattern and are able to fully satisfy their needs. However, there is little noticeable change in cattle weight from scenario to scenario. This suggests that it may be impossible to detect any effect of the Allotment Management Plan on cattle by examining their weight after they come off the range in the fall. Also, the functional relationship which computes fall weight is dependent only upon the proportion of TDN in the diet. The total amount of TDN consumed (i.e., forage consumed) would also influence the cattle weight gain during the summer. The functional relationship predicting fall cattle weights is a major candidate area for model refinement.

8.3 Future Use of the Riparian Model

The most useful function of a model is to make us think more carefully about the processes operating in the real system and how we should study them. To accomplish this objective, the model must be both qualitatively reasonable and easy to understand and use. The results discussed above indicate that the model's behavior is, for the most part, reasonable, though we have pointed out areas in need of improvement. The detailed description of functional relationships in Sections 2 to 5, together with the user manual in Appendices B to F, ensure that the model is easy to understand and use.

From the perspective of the Saval project researchers, the most useful application of the riparian model is to conduct "pilot" hypothesis tests; that is, to run 12-year scenarios on the model and examine under which base conditions and assumptions the AMP is shown to affect key indicators, and to assess whether or not such effects could be detectable in the field under current experimental designs. The model could quite easily be modified so that the first three years of the simulation use actual precipitation and temperature data, rather than simulated ones. This would serve the twin purposes of providing a realistic baseline for the following years of the simulation, and evaluating the validity of model predictions.

The model's assumptions should not be considered as fixed. Varying parameter values and the shape of functional relationships are a good way to evaluate the relative importance of different model components to model predictions. This activity often provides insight to the most important processes in the real system.

9.0 REFERENCES

Beanlands, G.E. and P.N. Duinker, 1983. An ecological framework for environmental impact assessment in Canada. Inst. for Resource and Env. St., Dalhousie University, Halifax, Nova Scotia and Federal Environmental Assessment Review Office, Hull, Quebec, 132 pp.

Hirsch, A., 1980. The baseline study as a tool in environmental impact assessment. In Symp. Proc., Biological Evaluation of Environmental Impacts, pp. 84-93. FWS/OBS-80/26, Council on Environ. Quality, and Fish and Wildl. Service, U.S. Dept. of the Interior, Washington, D.C.

Laycock, W.A., 1983. Evaluation of management as a factor in the success of grazing systems. In Symp. Proc., Managing Intermountain Rangelands - Improvement of Range and Wildlife Habitats. U.S. For. Serv., Intermountain Forest and Range Experiment Station, Ogden, Utah. Gen. Tech. Rep. INT-157, pp. 166-171.

Sonntag, N.C., D. Marmorek, P. McNamee, T. Webb, and J. Truett, 1982. Saval Ranch Research, Design, Integration and Synthesis - Modelling Workshop Report, 153 pp.

Trautmann, N.M., C.E. McCulloch, and R.T. Oglesby, 1982. Statistical determination of data requirements for assessment of lake restoration programs. Can. J. Fish. Aquat. Sci. 39: 607-610.

APPENDIX A

STATISTICAL DETERMINATION OF DATA REQUIREMENTS

Statistical Determination of Data Requirements for Assessment of Lake Restoration Programs

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TRAUTMANN, N. M., C. E. MCCULLOCH, AND R. T. OGLESBY. 1982. Statistical determination of data requirements for assessment of lake restoration programs. Can. J. Fish. Aquat. Sci. 39: 607–610.

To test the effectiveness of lake restoration programs, monitoring must be carried out both before and after any change is made. Statistical techniques are presented for calculation of these sampling requirements both for individual lakes and for groups of lakes analyzed collectively. Illustration of these techniques is made using data on productivity of New York State's Finger Lakes before and after the state ban on phosphate detergents. Existing pre-ban data on mean summer phytoplankton standing crop are shown to be insufficient for conclusive evidence of a post-ban productivity change in individual lakes no matter how many years of post-ban data could be obtained. When the lakes are analyzed as a group rather than individually, however, the conclusion is reached that there is a probability of only 0.7% that a chlorophyll drop at least as large as the one observed would have occurred without the effect of the phosphate detergent ban. Use of power calculations before sampling is begun will help to maximize the efficiency of data collection efforts in lake restoration programs.

Key words: lake sampling design, statistical analysis, summer chlorophyll, data requirements, lake restoration, eutrophication

TRAUTMANN, N. M., C. E. MCCULLOCH, AND R. T. OGLESBY. 1982. Statistical determination of data requirements for assessment of lake restoration programs. Can. J. Fish. Aquat. Sci. 39: 607–610.

Pour vérifier l'efficacité des programmes de restoration des lacs, il faut que ces lacs aient été suivis avant et après qu'un changement se soit produit. Nous décrivons des méthodes statistiques de calcul des besoins en échantillonnage, tant de lacs individuels que de groupes de lacs analysés collectivement. Nous illustrons ces méthodes à l'aide de données sur la productivité des lacs Finger de l'État de New York avant et après l'interdiction des détergents phosphatés. Nous démontrons que les données d'avant l'interdiction sur la biomasse phytoplanctonique estivale moyenne ne suffisent pas à prouver qu'il y eut changement dans la productivité après l'interdiction dans les lacs considérés séparément, quel que soit le nombre d'années, après l'interdiction, pour lesquelles on ait pu obtenir des données. Par contre, quand les lacs sont analysés en un groupe plutôt que séparément, il est possible de conclure que la probabilité n'est que de 0,7% qu'une chute de chlorophylle au moins aussi importante que celle observée se soit produite sans l'interdiction des détergents phosphatés. Des calculs machine précédant le début de l'échantillonnage contribueront à une efficacité maximale de la collecte des données dans les programmes de restoration des lacs.

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IN recent years many programs have been undertaken to limit lake eutrophication by reducing inputs of phosphorus. To evaluate the effectiveness of these lake management programs, extensive sampling is needed both before and after any change in phosphorus loading is made. Scientists responsible for designing such sampling programs need to be able to determine how much data is needed to detect the expected decreases in parameters such as summer chlorophyll. This paper presents techniques for estimation of sampling

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TABLE 1. Minimun levels of change in mean lake parameters detectable at a power of 0.90 and a significance level of 0.05 with various numbers of years of data.

No. of years before or after change		Min. detectable change (no. SD)
n_1	n_2	
1	2	13.0
	3	5.6
	4	4.4
	6	3.7
	8	3.5
	10	3.3
	∞	2.9
2	2	4.8
	3	3.6
	4	3.1
	6	2.7
	8	2.5
	10	2.4
	∞	2.1
3	3	2.9
	4	2.6
	6	2.3
	8	2.2
	10	2.1
	∞	1.7
4	4	2.4
	6	2.0
	8	1.9
	10	1.8
	∞	1.5
6	6	1.8
	8	1.7
	10	1.6
	∞	1.2
8	8	1.5
	10	1.4
	∞	1.0
10	10	1.4
	∞	0.9

requirements for detection of changes of specified magnitudes either in individual lakes or in a group of lakes analyzed collectively.

When only one lake is being analyzed, the number of years of data needed depends on specification of the size of change to be detected and the significance and power levels of the test. If the hypothesis to be tested is that no detectable change in summer chlorophyll concentration has occurred, then a significance level of 0.05 means, with repeated testing, 5% of the time the erroneous conclusion would be reached that a significant change in chlorophyll has occurred. Similarly, a power level of 0.90 indicates a 10% probability of failing to detect a significant change when one has occurred. The magnitude of change which can be detected at specified significance and power levels depends on the number of years for which data are available. Once these statistical values have been specified, then calculations can be performed using either tables of the noncentral t distribution (Locks et al. 1963) or the normal approximation to this distribution (Abramowitz and Stegun 1964) to determine how many years of sampling are needed for detection of a change of the anticipated magnitude. Table 1 presents the results of these calculations for a power of 0.90 and a significance level of 0.05.

An example of the use of this table is the design of a sampling program to analyze the effect of New York State's ban on phosphate detergents on productivity of the Finger Lakes. Investigations of five of these lakes had been underway for 2 or more years when legislation was passed in 1973 to ban the use of phosphates in household laundry detergents (Table 2). The law became effective in June of that year. It was estimated at the time that this action would decrease phosphorus loading in the various lakes by 19–36%, or 0.4–2.0 standard deviation (SD) units, as indicated in Table 3 (Schaffner and Oglesby 1978; Oglesby and Schaffner 1978). For most of the lakes, 3 years of pre-ban data and two of post-ban data were available on mean summer phytoplankton standing crop (CHL.);[1] and it was desired to determine whether the ban could be shown to have caused any changes in this index of lake productivity. The data were transformed to the log scale so that CHL. variances, calculated among years within each lake, would be equal between lakes.

Using t-tests, pre- and post-ban chlorophyll concentrations were compared to determine whether any significant changes had occurred. These tests are valid only for analysis of the individual lakes and cannot be extended to comparisons of the lakes or conclusions about changes in the group as a whole. Only Owasco Lake showed a significant decline ($P < 0.05$), although both Conesus and Hemlock Lakes were close ($P < 0.06$).

Using Table 1, however, it can be seen that the available data are too scanty to warrant analyses of this sort. With only 3 and 2 years of pre- and post-ban sampling, the minimum change detectable at a power of 0.90 and a significance level of 0.05 would be 3.6 SD units. Because this is far larger than the magnitude of change expected in any of the Finger Lakes (Table 3), it is apparent that the data available are insufficient for drawing conclusions about productivity changes in the individual lakes. In fact, it can also be seen from Table 1 that with only 3 years of pre-ban data, even an infinite number of years of post-ban sampling would be insufficient for statistical detection of changes of the 0.4–2.0 SD size expected in the Finger Lakes. Even if the post-ban monitoring had been continued for many more years, therefore, we would not have been able to find significant CHL. changes unless we had either had more years of pre-ban data or been willing to decrease the power of our statistical analyses.

In a case such as this where a change in phosphorus loading is incurred simultaneously by a number of lakes, the number of years of sampling required can be reduced by analyzing the lakes as a group rather than individually. The probability of being able to detect a decrease of a certain size in any given parameter then depends on the number of lakes tested, the

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[1] Estimated as mean chlorophyll a plus pheopigment concentrations in the epilimnion and hereafter designated CHL.

TABLE 2. Summer chlorophyll concentrations in the Finger Lakes.

Lake	Year	CHL$_s$ (mg·m^{-3})	Lake	Year	CHL$_s$ (mg·m^{-3})
Conesus	1971	9.3	Skaneateles	1971	1.3
	1972	4.6		1972	2.3
	1973[a]	6.4		1973[a]	1.5
	1975	N.A.[b]		1975	N.A.
	1977	3.8		1977	1.4
	1978	3.3		1978	0.9
Hemlock	1971	7.8	Cayuga[c]	1970	3.7
	1972	7.0		1972	10.3
	1973[a]	6.1		1973[a]	8.2
	1975	N.A.		1974	8.1
	1977	5.5		1977	8.6
	1978	3.1		1978	6.5
Owasco	1971	6.6	Canadice	1973[a]	3.1
	1972	4.5		1977	4.4
	1973[a]	5.8		1978	2.8
	1975	N.A.			
	1977	3.9			
	1978	2.1			

[a] Although the New York State detergent ban went into effect in June of 1973, data for this year was used as pre-ban because much of the P to support that summer's phytoplankton production had presumably entered the lakes during the spring runoff and because some of the pre-phosphate ban detergents were undoubtedly still being used in households during that summer.

[b] N.A. indicates years for which data were not available.

[c] A chlorophyll value was available for Cayuga Lake for 1965 but was omitted because it was so far removed in time from the other data points.

TABLE 3. Minimum changes in summer phytoplankton standing crop (ln CHL$_s$) that would be detectable with available data for the New York Finger Lakes.

Lake	Pre-ban mean for ln CHL$_s$ (ln mg·m^{-3})	Estimated SD[a] (ln mg·m^{-3})	Expected decrease in loading of biologically available phosphorus (%)[b]	Expected decrease in loading of biologically available P (No. SD units)
Conesus	1.87	0.29	31	2.0
Hemlock	1.94	0.25	22	1.7
Owasco	1.72	0.30	32	1.8
Skaneateles	0.50	0.30	25	0.4
Cayuga	1.91	0.39	36	1.8
Canadice	1.13	0.32	19	0.7

[a] The standard deviation for each lake was determined by calculating the variability of the pre- and post-ban data about their respective means, then taking an average weighted by the number of observations for each.

[b] Derived from data in Schaffner and Oglesby (1978).

number of years of sampling per lake, and the magnitude of change expected, as shown in Table 4. These calculations are carried out using the noncentral F statistic (Scheff 1959). To have a 90% probability of detecting a drop in summer chlorophyll (ln CHL$_s$) of 0.5 SD units, for example, close to 30 lakes would need to be sampled for 4 years (2 before and 2 after the change in loading), or 20 lakes for a total of 6 years. If the size of change to be detected is increased to 1 SD, then approximately eight lakes need to be sampled for a total of 4 years, or six lakes for 6 years.

In the case of the Finger Lakes, 3–6 years of data was available for six lakes, so the probability of detecting a decrease of 1 SD in CHL$_s$ was somewhere close to 90%. To analyze the lakes collectively, a two-way analysis of variance was used to test lake, time (before vs. after the ban), and the interaction between lake and time as potential sources of the variation in summer chlorophyll levels. Interaction between lake and time was not significant at the 0.05 significance level. After the summer chlorophyll analysis was revised to delete the insignificant interaction variable, the significance

TABLE 4. Probabilities of detecting changes of specified sizes with varying amounts of data.

No. of lakes to be studied	No. of years of sampling both before and after change in loading	No. SD units to be detected	Probability of detecting change of specified magnitude
20	2	0.5	0.80
30	2	0.5	0.89
60	2	0.5	0.99
15	3	0.5	0.83
20	3	0.5	0.89
40	3	0.5	0.99
6	2	1.0	0.82
8	2	1.0	0.89
14	2	1.0	0.98
4	3	1.0	0.82
6	3	1.0	0.92
10	3	1.0	0.99
3	2	1.5	0.82
4	2	1.5	0.89
6	2	1.5	0.97
2	3	1.5	0.86
3	3	1.5	0.93
5	3	1.5	0.99

level of the one-sided test for variation due to time was 0.007, indicating a probability of only 0.7% that a chlorophyll drop at least as large as the one observed would have occurred without the effect of the phosphate detergent ban. Even without any change in phosphorus loading, chlorophyll levels in lakes go through natural cycles of variation. In analyzing changes in productivity caused by changes in phosphorus inputs, the variation due to these natural fluctuations must be taken into account. The 0.007 significance level in the chlorophyll analysis means that there is a 0.7% chance that variation in the data is being misinterpreted and that no significant change occurred in lake chlorophyll values.

The statistical power calculations presented here demonstrate that the most effective way in which to gauge the effectiveness of regional programs in lake management is to sample a group of lakes for a relatively few years rather than a single lake over a very long period of time. Use of the power calculations before sampling is begun will help to maximize the efficiency of data collection efforts. In many cases it may not be possible to detect changes in an individual lake unless monitoring has been carried on for a number of years before lake restoration efforts are begun.

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ABRAMOWITZ, M., AND I. A. STEGUN. [ed.] 1964. Handbook of mathematical functions with formulas, graphs, and mathematical tables. U.S. Govt. Printing Office, Washington, DC.

LOCKS, M. O., M. J. ALEXANDER, AND B. J. BYERS. 1963. New tables of the noncentral *t* distribution. Aeronautical Research Laboratories, Office of Aeronautical Research, U.S. Air Force. ARL Tech. Rep. 63-19.

OGLESBY, R. T., AND W. R. SCHAFFNER. 1978. Phosphorus loadings to lakes and some of their responses. Part 2. Regression models of summer phytoplankton standing crops, winter total P, and transparency of New York lakes with known phosphorus loadings. Limnol. Oceanogr. 23: 135–145.

SCHAFFNER, W. R., AND R. T. OGLESBY. 1978. Phosphorus loadings to lakes and some of their responses. Part 1. A new calculation of phosphorus loading and its applications to 13 New York lakes. Limnol. Oceanogr. 23: 120–134.

SCHEFFE, H. 1959. The analysis of variance. John Wiley and Sons, Inc., New York, NY.

APPENDIX B - RIPARIAN APPLE USER MANUAL

This appendix, together with Appendices C to G, provide sufficient directions for anyone with a basic knowldge of microcomputers to use and, if desired, alter the riparian model described in the previous sections of this report.

The riparian model is linked to Apple SIMCON, a simulation control program which is very user-friendly. There are a minimum number of commands to remember, yet Apple SIMCON is capable of doing most of what a user would want to when running the model.

The program containing the riparian model plus Apple SIMCON is stored in three files called "START", "MODEL", and "GRAPHICS". START sets up initial conditions for the model, gives the user a chance to change parameter values, then calls in MODEL. MODEL is the riparian model itself. After it is finished simulating, GRAPHICS is called. Here, the user can view output indicators over time. In order to run the model, the Apple must have been booted with the diskette containing the riparian model; the HELLO program on this diskette changes the Apple's memory structure in order that graphics can be used. After booting, the user should first LOAD START, then RUN. The user will almost immediately get a prompt on the screen, ">". Whenever ">" appears as a prompt, the user can enter one of the following three commands:

a) STOP - stops execution of the model and puts the user into Applesoft;

b) GR - puts the user immediately into graphics mode for viewing model variables which have been stored on the diskette from a previous run (more about this later); or

c) m n - numbers which give the starting (m = 0) time step and ending time step (n) for the model simulation. m must always equal 0 to properly initialize the model.

If the user chooses to do a simulation, START will first set all the input data; this is done in lines 100 to 998; it takes about 15 seconds to go through all this initialization. The user will then be asked to change any model variables before model simulation actually begins; the line "ENTER COMMANDS, THEN CONT" will appear. Here, the user can change any variable used in the model by simply entering Applesoft commands. When all variable changes have been made, the user enters "CONT". This loads the file called MODEL into the Apple and begins model execution. It takes about 5 minutes per year, or about one hour per Saval rotation (12 years) to run the model. The model should never be halted by entering CONTROL-C when it is running. The three model files, START, MODEL, and GRAPHICS, are linked together using the file called CHAIN; if the model's execution is stopped by entering CONTROL-C, it is impossible to restart it.

Once the model has finished executing, the file called GRAPHICS will be automatically loaded into the Apple and the following prompt will appear: "ENTER VAR#". The user is now in graphics mode and can look at the results of the simulation. If the user enter "GR" at the very beginning, the user would have been moved to this point without going through model execution.

When this new prompt appears, the user has a choice of options to enter:

a) i j k - this plots variable i scaled to a maximum value of j and a minimum value of k. If j or k are not entered, the minima and/or maxima of variable i from the simulation run are used. The variable is scaled to its maximum value for the simulation.

When a variable is plotted, the maximum and minimum values for the simulation are written below the prompt at the bottom of the screen, the maximum value is written on the top right of the graph, the minimum value is written on the bottom right of the graph, and the name of the output indicator is written on top of the graphics screen.

b) ZERO j k - the same as the above command, except that a straight line across the graph at Y value = 0 will be plotted. In this case, j and k must be given, as the program does not remember the scaling of the current graph.

c) START - this command gets the user out of graphics mode and begins model simulation once again. The file called START is loaded into the Apple and run; the prompt ">" will soon appear.

d) Q - this outputs the current graph onto the printer. The model is set up to handle either an Apple Silentype or Epson printer. If the user has some other kind of printer, lines 13000 to 13040 in GRAPHICS will have to be modified.

e) ZS file - this saves all output indicators from the current simulation to the disk onto a file named "file" (or any other name).

f) ZL file - this loads a set of output indicators from a file named "file" on the diskette into the Apple for viewing. This means that results from a scenario can be stored using "ZS" then looked at later with "ZL". This is where the command GR comes in handy. If the results of a model scenario have been previously saved with the ZS command, entering GR at the very beginning puts the user immediately into GRAPHICS. The user can then use the ZL command to bring the results of the previous model scenario into the Apple for examination. This saves the user the chore of rerunning the same scenarios over again.

g) S file - this saves the current graph onto the diskette into a file named "file". Note that saving graphs takes up much more disk space than saving the indicator values using the ZS command.

h) R file - this loads a graph stored in the file "file" from the diskette into the Apple.

i) G - this clears the graphics screen.

j) STOP - this command simply stops program execution.

k) ? - this allows the user to look at the definitions of the model indicators. This command will print out the indicator numbers followed by the appropriate definition. Entering a "/" gives definitions of more indicator variables, while entering any other key puts the user back into graphics mode. This is especially useful, as it is difficult to always remember the definition of each indicator number.

APPENDIX C - RIPARIAN MODEL FILE DESCRIPTIONS

The diskette provided contains nine files. Their functions are as follows:

a) CHAIN - this file is used whenever a different part of the model is to be executed and the values of all variables are to be retained. CHAIN is first loaded; it then is used to begin execution of another part of the model. See Chapter 10 of the Apple DOS manual for more information on what this file does.

b) GRAPHICS - an Applesoft program which is used to generate plots of model indicators over time.

c) GRAPHICS DOC - an annotated, non-executable version of GRAPHICS. This file is listed at the end of this chapter.

d) HELLO - the diskette boot file. It contains particular commands which allow the model to be executed without overwriting the graphics portions of the Apple memory.

e) MODEL - the riparian model.

f) MODEL DOC - an annotated, non-executable version of MODEL. This file is listed at the end of this chapter.

g) SHAPE TABLE - a file which contains characters which can be written on the graphics screen. This is used for writing indicator definitions, minima, and maxima on the graphs.

h) START - a file which begins model execution. It assigns default values to all model parameters and initial data, and allows the user the opportunity to modify those.

i) START DOC - an annotated, non-executable version of START. This file is listed at the end of this chapter.

APPENDIX D

RIPARIAN MODEL INDICATOR DEFINITIONS

INDICATOR NUMBER	DEFINITION
0	stream channel width in mountainous spatial unit (feet)
1	stream channel width in alluvial spatial unit (feet)
2	stream channel width in hay meadow spatial unit (feet)
3	number of fish eggs per mile of stream
4	number of fish per mile of stream in age class 1
5	number of fish per mile of stream in age class 2
6	number of fish per mile of stream in age class 3+
7	weight per fish in age class 2 (grams)
8	weight per fish in age class 3+ (grams)
9	total fish biomass per mile of stream (kilograms)
10	# of fish caught by anglers per mile of stream
11	average water table depth over all spatial units (feet below surface)
12	net change in legume biomass in mountainous spatial unit if 1 year simulation (lb/acre) cumulative legume production in mountainous spatial unit if multi-year simulation (lb/acre)
13	net change in sedge and rush biomass in mountainous spatial unit if 1 year simulation (lb/acre) cumulative sedge and rush production in mountainous spatial unit if multi-year simulation (lb/acre)
14	net change in forb and grass biomass in mountainous spatial unit if 1 year simulation (lb/acre) cumulative forb and grass production in mountainous spatial unit if multi-year simulation (lb/acre)
15	net change in shrub biomass in mountainous spatial unit if 1 year simulation (lb/acre) cumulative shrub production in mountainous spatial unit if multi-year simulation (lb/acre)
16	net change in legume biomass in alluvial spatial unit if 1 year simulation (lb/acre) cumulative legume production in alluvial spatial unit if multi-year simulation (lb/acre)
17	net change in sedge and rush biomass in alluvial spatial unit

if 1 year simulation (lb/acre)
cumulative sedge and rush production in alluvial spatial unit if multi-year simulation (lb/acre)

18 net change in forb and grass biomass in alluvial spatial unit if 1 year simulation (lb/acre)
cumulative forb and grass production in alluvial spatial unit if multi-year simulation (lb/acre)

19 net change in shrub biomass in alluvial spatial unit if 1 year simulation (lb/acre)
cumulative shrub production in alluvial spatial unit if multi-year simulation (lb/acre)

20 net change in legume biomass in hay meadow spatial unit if 1 year simulation (lb/acre)
cumulative legume production in hay meadow spatial unit if multi-year simulation (lb/acre)

21 net change in sedge and rush biomass in hay meadow spatial unit if 1 year simulation (lb/acre)
cumulative sedge and rush production in hay meadow spatial unit
if multi-year simulation (lb/acre)

22 net change in forb and grass biomass in hay meadow spatial unit if 1 year simulation (lb/acre)
cumulative forb and grass production in hay meadow spatial unit if multi-year simulation (lb/acre)

23 net change in shrub biomass in hay meadow spatial unit if 1 year simulation (lb/acre)
cumulative shrub production in hay meadow spatial unit if multi-year simulation (lb/acre)

24 potential number of bird species in mountainous spatial unit

25 potential number of bird species in alluvial spatial un

26 potential number of bird species in hay meadow spatial unit

27 % herbaceous cover in mountainous spatial unit

28 % herbaceous cover in alluvial spatial unit

29 % herbaceous cover in hay meadow spatial unit

30 total hay produced (tons)

31 total riparian forage consumed (lbs/acre)

32 total non-riparian forage consumed (lbs/acre)

33 cattle months in mountainous spatial unit

34	cattle months in alluvial spatial unit
35	fall calf wean weight (lbs)
36	revenue from fall calf sales ($)
37	hay bought to keep herd over winter (tons)
38	temperature (degrees Farenheit)
39	precipitation (inches)
40	water table depth in mountainous spatial unit (feet below surface)
41	water table depth in alluvial spatial unit (feet below surface)
42	water table depth in hay meadow spatial unit (feet below surface)

APPENDIX E

RIPARIAN MODEL VARIABLE DICTIONARY

AA - variable: accumulator for calculation of average stream bank shading

AB(IS) - data: area of bank for each riparian spatial unit (acres)

AC - constant: =640 conversion factor used in calculation of cattle days/mile

AD - variable: survival rate for all age classes for effects from depth of flow

AP(IS,IR) - data: proportion of each spatial unit in riparian/non-riparian

AQ - variable: average flow for year

AR(IS,IR) - data: areas of land units in model (acres)

AS(IS) - data: total area of each spatial unit (acres)

AU - constant: AUMs per week per unit of livestock (lbs)

AV - variable: survival rate for all age classes for effects from vegetation shading

AW - constant: days per week (=7.6)

B1 - constant: Y intercept of equation relating proportion TDN to proportion crude protein in forage

B2 - constant: slope of equation relating proportion TDN to proportion crude protein in forage

BA(IV,IS,IR) - variable: biomass of each plant group (lbs/acre)

BC - constant: =7.57e-3 conversion factor used in calculation of cattle days/mile

BE - constant: =4.05e-3 =1/density of soil for all areas

BM(IV) - constant: forage mortality rate over the winter time step

BS - variable: bank stability factor in hydrology model

C1(2) - constant: array for calculation of forage protein content

C2(2) - constant: array for calculation of forage protein content

CA - variable: cumulative number of fish caught within the year

CB - constant: =10 used in bank height initialization

CB(IV,IS,IR) - variable: lbs/acre forage consumed in a year

CC(IV) - constant: an array which contains a pointer to aggregate forage types for model output purposes

CD(IS) - variable: cattle months in riparian zone on first 2 spatial units (the only spatial units cattle are on)

CE(IS) - data: equilibrium stream width for each riparian spatial unit (feet)

CM(IS) - variable: cattle days per mile of stream bank (days/mile)

CR - variable: used in fishing effort calculation

CS - constant: =500 used in calculation of fishing effort

CT - variable: number of fish caught within one time step

CU - constant: =15

CV - variable: fishing effort (angler days/mile of stream)

CW(IS) - variable: current stream width for each riparian spatial unit (feet)

CZ - variable: cattle induced stream widening (feet)

DA - constant: necessary proportion of TDN in diet for maintenance of weight

DB(DU,IS) - data: initial weeks which cattle are on first 2 spatial units

DC(IR) - variable: % total forage consumed which is from riparian/non-riparian areas

DE(DU,IS) - data: final weeks which cattle are on first 2 spatial units

DF - constant: proportion of day spent feeding

DG(IV) - constant: maximum proportion of forage that cattle can consume

DI - variable: used for temporary variable storage in calculation of forage production

DI(IV,IS,IR) - variable: array containing forage biomass at the end of the previous time step (lb/acre)

DQ - variable: flow depth

DT - variable: used in assignment of average flow depth (HA)

DU - variable: year of rotation (cycles from 0 to 5)

EA - constant: forage TDN content at which fall calf wean weight equals WN

EC - constant: =0.2 erosion coefficient for cattle effects (tons/cattle day)

EH - variable: lbs of hay produced on Saval Ranch

EL - constant: =50000 carrying capacity limit for fish eggs (eggs/mile)

EM - variable: maximum biomass available to cattle for consumption; calculated for every combination of IV,IS,IR (lb)

EN - variable: number of eggs/mile

EP - constant: =800 number of eggs per pound of female

ET(4,7) - constant: optimal evapotransportation rate (ft/week)

EW - constant: =0.75 egg weight (gm)

EX(IR) - constant: maximum proportion of forage which can be consumed on riparian/non-riparian areas

EY - variable: hay which must be bought to maintain cattle through winter (tons)

F1 - constant: =48 weeks in year

F1(V3) - variable: the growth multiplier for each aggregate forage type from fertilizer application

F2 - constant: =12.84 offset from Jan.1 to Apr.1 (weeks)

F3 - constant: =PI/F1

F4 - constant: =36 divisor for computation of average flow depth (HA) =3 spatial units x 12 months

F6 - constant: =15

F9 - constant: =99 used to check for no grazing

FA - variable: used for temporary assignments

FA(3) - variable: number of fish for each age class

FD(IS,1) - switch: FD(n,0) set from DE(rotation#,IS) to last week of cattle grazing: FD(n,1) control flag to signal computation complete for area

FM(IM) - data: average stream flow for each month

FS(3) - constant: survival rate for each age class

FT - variable: used for temporary assignments

FW - variable: used for temporary assignments

FW(3,1) - variable: (n,0)=weight of fish for each age class (n,1)=flag to note fishing mortality

GM - constant: =454 (gm/pound)

GP - variable: growth multiplier for all age classes derived as a function of fish weight

HA - variable: average flow depth for year over all riparian spatial units (inches)

HB(IS) - variable: bank height for each riparian spatial unit (feet)

HM - loop counter: used to index by month within hydrology model

HP - switch: to control yearly variance in precipitation 0=same year to year 1=varries

HR - switch: to control variance in temperature 0=same year to year 1=varies

HT - variable: used to allocate fish harvest mortality; also used as loop index

HV - constant: =0.1 standard deviation for temperature data when HR is on (=1)

HW - loop counter: used in hydrology/fish models to index by week

I0-J1 - constants: variables for the numbers 0 to 10: simply makes the model run faster

IA - loop counter: used by fish model to index by age

IL - switch: used to signal last month of year (=1, otherwise=0)

IM - loop counter: the last "month" is 5 months long, November to March

IN - constant: =12 inches/foot

IR - loop counter: for riparian/non-riparian within spatial units

IR(IS,IR) - data: applied irrigation water (ft/time step)

IS - loop counter: for spatial unit

IT - variable: cumulative time step counter during the year (0 to 14)

IU - loop counter: used in hydrology/fish models

IV - loop counter: for forage type (0 to 5)

IW - loop counter: for bi-weekly time step within each month

KG - constant: =1000 (gm/kg)

LI - variable: total amount of surface water applied in each time period

LS(IS) - data: length of stream for each riparian spatial unit (miles)

MB(IV,IS,IR) - constant: maximum possible forage biomass (lb/acre)

ML(IV) - constant: mortality rates for each plant group (/week)

MR - constant: =0.1 bank widening rate constant

MS(3) - switch: =(0,1) for selective execution of submodels (0-hydrology, 1-vegetation,2-fish,3-cattle)

NA$(NV) - data: array which stores short descriptions of model indicators for

NI - variable: used to point to appropriate part of Z-array output should be saved

NN(NS) - data: array which tells the number of coordinate pairs in each SLP

NT - variable: =14 maximum number of time steps

NV - constant: =42 number of model indicators

OD(IV) - constant: optimal depth of water table

P3 - constant: PI/2

P3(IV) - constant: pointer array for use in calculation of forage protein content

PB(IV,IS,IR) - variable: lbs/acre forage production in a year

PF(IT,IV) - constant: preference for different forage types in each week/time step of the year

PG(IV) - constant: growth rate for each plant group (/week)

PI - constant: =3.14159

PR - variable: total weekly forage demand by all cattle (lb)

PS(1,IS) - variable: array containing herbaceous and shrub cover values for the riparian spatial units

PV(IV,IS,IR) - variable: plant vigor factor (0 <=> 1)

RB(IM,IW) - variable: precipitation data base

RD(IV,1) - constant: minimum and maximum water table depths for forage growth

RP(IV,IS,IR) - variable: forage consumed by cattle (lb/acre)

RR - variable: used for temporary assignments

RR(IW) - variable: the precipitation for each 2 week period in a monthly time step (inches)

RWT(4) - constant: range of water tolerance above & below optimum (ft)

S1(2) - constant: parameters used in calculating herbaceous and shrub cover in riparian areas

SA - switch: used for determining how often model indicators are saved; =1, saved each time step; =2 saved once a year

SB - variable: temporary variable used in calculation of amount of hay which must be bought

SF(IS) - variable: total forage cover in riparian areas

SL - variable: variable returned by SLP

SS - variable: fall calf sale revenues ($)

SW(3) - data: week of the year in which to save model indicators for hydrology, vegetation, cattle, and fisheries submodels

TB(IM,IW) - variable: baseline temperature data by month and week (degrees F)

TD - variable: cumulative TDN consumed by all cattle (lb)

TE(IW) - variable: temperature for month (by week) (degrees F)

TI - loop counter: Apple SIMCON time step counter

TM - variable: temperature factor (0-1)

TS - variable: cumulative forage consumed by all cattle (lb)

UC - variable: cattle equivalents per head of cattle: changes to reflect start of foraging by calves

UF(IS,IR) - data: the lbs of N fertilizer applied

UT(IV,IS,IR,2) - variable: forage utilization for the previous 3 years; used in calculation of plant vigor

UU - variable: cattle use factor to account for calf growth through time cattle are on Ranch

VC - constant: proportion of hay meadow forage removed for hay production in the first week of August

WA - variable: fall calf weight (lb)

WB(IS) - variable: potential # bird species in each riparian zone spatial unit

WC - variable: pointer for optimal rate of evapotranspiration

WC(IV) - constant: an array which contains a pointer, for each forage type, to the appropriate water factor

WD - variable: water table depth (feet) averaged over all areas

WD(IS) - variable: water table depth by each spatial unit

WN - variable: average weight of fall calves (lb)

WP(IV) - variable: proportion crude protein in forage

WTF - variable: water table factor (0-1)

WV(IV) - data: minimum biomass levels for each plant group (lbs/acre)

X - variable: used for temporary variable storage

XE - variable: weekly forage demand not met (lb)

XS - variable: contains X value argument to SLP function

XX - variable: dummy variable used for intermediate information

XX(5,NS) - data: array of X-coordinate points for SLP functions: up to 5 points per SLP

YC - data: number of cattle on Saval Ranch

YY(5,NS) - data: array of Y-coordinate points for SLP functions: up to 5 points per SLP

Z(NV,NT) - variable: array which stores the model indicators

ZD - constant: zero divide check: used in any denominator to remove possibility of divide by 0

ZL(NV) - variable: array which stores the minimum value of the model indicators

ZM(NV) - variable: array which stores the maximum value of the model indicators

ZR - variable: normally distributed random variable with mean=0 std.dev=1 used for temperature variance when HR=1

ZS - variable: first year of model simulation

APPENDIX F

DESCRIPTIONS OF MAJOR SECTIONS OF MODEL CODE

A. File START

Line Number Range	Description
10 - 170	define arrays
180 - 610	assign indicator names
2000 - 2999	data assignments for hydrology/fisheries submodel
3000 - 3999	data assignments for vegetation/wildlife submodel
4000 - 5999	data assignments for cattle/economics submodel
10000 - 10080	assignments for areas of spatial units and riparian zones
10090 - 10100	call and begin executing file MODEL
20000 - 20110	linear interpolation function

B. File MODEL

Line Number Range	Description
5 - 100	subroutines to calculate random temperature and precipitation regimes
110 - 280	opens the yearly, monthly, and bi-weekly time step loops and calls the submodels
290 - 420	saves model indicators
430 - 470	ends the yearly, monthly, and bi-weekly time step loops
2000 - 2170	the hydrology submodel
2180 - 2999	the fisheries submodel
4000 - 4999	the vegetation/wildlife submodel
6000 - 6999	the cattle/economics submodel
10000	loads and executes the file GRAPHICS
12000	subroutine which returns a random normal deviate

20000 - 20110	the linear interpolation function

C. File GRAPHICS

Line Number Range	Description
10 - 60	loads SHAPE TABLE, draws the graphics screen, waits for input
70	reruns the model, beginning with file START
80	ends model execution
90	calls subroutine to print out model indicator definitions
100	calls subroutine to print graph
110 - 120	saves the output array as a binary file on the diskette
130 - 140	loads a binary file from the diskette into output array memory space
150 - 180	saves the graphics image as a binary file
190 - 220	loads a binary file from the diskette into the Apple graphics page
230	re-initializes the graphics screen
240 - 250	checks that command line has proper syntax
260 - 370	picks up maxima and minima from command line
380	prints maximum and minimum on bottom of graphics page
390 - 470	plots the indicator
490 - 570	prints the graphics page on an Epson printer
580 - 590	subroutine for writing text on graphics page
600 - 660	prints the graphics page on an Apple Silentype printer
670 - 680	subroutine for printing first and

	last time step on X axis
690 - 720	subroutine for printing Y min and Y max on graph
730 - 810	subroutine for calculating the minimum and maximum value of an indicator
820 - 920	subroutine for displaying model indicator definitions

APPENDIX G

LISTINGS OF MODEL FILES

```
]LIST

4  REM
5  REM  INITIALIZE RANDOM NUMBER GENERATOR
6  REM
10 R =  RND ( - 1)
14  REM
15  REM  SET SIZES OF ARRAYS
16  REM
20 IM = 7:IW = 1:IS = 2:IR = 1:IA = 3:NV = 42:NT = 14:NS = 19:WC = 3:IV = 5
24  REM
25  REM  SIMCON ARRAYS
26  REM
30  DIM Z(NV.NT),ZM(NV),NA$(NV),ZL(NV),XX(4,NS),YY(4,NS),NN(NS),MS(3)
34  REM
35  REM  HYDROLOGY AND FISH ARRAYS
36  REM
40  DIM FM(IM),AB(IS),LS(IS + 1),CW(IS),CE(IS),HB(IS),TB(IM,IW),RB(IM,IW),CM(IS)
50  DIM FA(IA),FW(IA,1),FS(IA),RR(IW)
54  REM
55  REM  VEGETATION/WILDLIFE ARRAYS
56  REM
60  DIM PG(IV),ML(IV),ET(WC,IM),RWT(WC),BA(IV,IS,IR),IR(IS,IR),UF(IS,IR),CB(IV,IS,IR),PB(IV,IS,IR),WC(IV),F1(1),CC(IV),MB(IV,IS,IR)
70  DIM DI(IV,IS,IR),WV(IV),PS(1,IS),WB(IS),UT(IV,IS,IR,2),BM(IV),PV(IV,IS,IR),P3(IV),C1(2),C2(2),S1(2),SF(IS),OD(IV),RD(IV,1),FB(IV
,IS,IR)
74  REM
75  REM  CATTLE/ECONOMICS ARRAYS
76  REM
80  DIM DB(5,1),DE(5,1),PF(NT,IV),DG(IV),RP(IV,IS,IR),WP(IV),CD(IS),DC(IR),EX(IR)
84  REM
85  REM  AREA ARRAYS
86  REM
90  DIM AR(IS,IR),AS(IS),AP(IS,IR),SW(3)
94  REM
95  REM  ASSIGNMENTS FOR QUICKER MODEL
96  REM
100 I0 = 0:I1 = 1:I2 = 2:I3 = 3:I4 = 4:I5 = 5:I6 = 6:I7 = 7:I8 = 8:I9 = 9:J1 = 10
104  REM
105  REM  GET OUTPUT LABELS
106  REM
110  GOSUB 180
114  REM
115  REM  A SIMCON STATEMENT
116  REM
120  INPUT "> ";A$: IF  LEFT$ (A$,2) = "GR" THEN ZS = 0:NT = 14: PRINT  CHR$ (4);"BLOAD CHAIN,A520": CALL 520"GRAPHICS"
124  REM
125  REM  USER CAN STOP EXECUTION
126  REM
130  IF A$ = "STOP" THEN  TEXT : END
134  REM
135  REM  SIMCON STATEMENTS
136  REM
140 ZS =  VAL ( LEFT$ (A$,2)):NT =  VAL ( RIGHT$ (A$,3))
150  IF NT < 1 THEN NT =  VAL ( RIGHT$ (A$,2))
154  REM
155  REM  MODEL ASSIGNMENTS
156  REM
160 SA = 1:AW = 7.6
170  GOTO 620
174  REM
175  REM  LABELS FOR MODEL INDICATORS
```

```
176  REM
180 NA$(10) = "CHAN WIDTH UPPER"
190 NA$(11) = "CHAN WIDTH ALLUV"
200 NA$(12) = "CHAN WIDTH LOWER"
210 NA$(13) = "# FISH AGE(0)"
220 NA$(14) = "# FISH AGE(1)"
230 NA$(15) = "# FISH AGE(2)"
240 NA$(16) = "# FISH AGE(3+)"
250 NA$(17) = "FISH WT. AGE(2) GM"
260 NA$(18) = "FISH WT. AGE(3+) GM"
270 NA$(19) = "TOTAL FISH BIOMASS KG"
280 NA$(J1) = "# FISH CAUGHT"
290 NA$(11) = "WATER TABLE DEPTH"
300 NA$(12) = "LEGUMES UPPER"
310 NA$(13) = "SEDG&RUSH UPPER"
320 NA$(14) = "GR & FORB UPPER"
330 NA$(15) = "SHRUB UPPER"
340 NA$(16) = "LEGUMES ALLUV"
350 NA$(17) = "SEDG&RUSH ALLUV"
360 NA$(18) = "GR & FORB ALLUV"
370 NA$(19) = "SHRUB ALLUV"
380 NA$(20) = "LEGUMES LOWER"
390 NA$(21) = "SEDG&RUSH LOWER"
400 NA$(22) = "GR & FORB LOWER"
410 NA$(23) = "SHRUB LOWER"
420 NA$(24) = "#BIRD SPEC UPPER"
430 NA$(25) = "#BIRD SPEC ALLUV"
440 NA$(26) = "#BIRD SPEC LOWER"
450 NA$(27) = "%HERB COVR UPPER"
460 NA$(28) = "%HERB COVR ALLUV"
470 NA$(29) = "%HERB COVR LOWER"
480 NA$(30) = "HAY HARVEST TONS"
490 NA$(31) = "RIPAR FORAGE CONS"
500 NA$(32) = "NON-RIP FORG CONS"
510 NA$(33) = "CATTLE MON. UPPER"
520 NA$(34) = "CATTLE MON. ALLUV"
530 NA$(35) = "FALL WEAN WEIGHT"
540 NA$(36) = "$ CALF SALES"
550 NA$(37) = "TONS HAY BOUGHT"
560 NA$(38) = "TEMPERATURE"
570 NA$(39) = "PRECIPITATION"
580 NA$(40) = "H20 TABLE (0)"
590 NA$(41) = "H20 TABLE (1)"
600 NA$(42) = "H20 TABLE (2)"
610  RETURN
614  REM
615  REM  SUBMODEL EXECUTION SWITCHES
616  REM
620  FOR IA = 10 TO 13:MS(IA) = 11: NEXT
1994  REM
1995  REM  HYDROLOGY/FISHERIES SUBMODEL DATA INITIALIZATION
1996  REM
2000 HP = 0:AC = 640:BC = 7.57E - 3:EC = 0.2:BE = 0.00405:MR = 0.1:IN = 12:CB = 10:HR = 0:HV = 0.1
2004  REM
2005  REM  BANK AREA, STREAM LENGTH, STREAM WIDTH, EQUILIBRIUM STREAM WIDTH
2006  REM
2010  DATA     73,15,5,5
2020  DATA   4.75,10,10,10
2030  DATA   100,3,15,15
2040 LS(13) = 10: FOR IS = 10 TO 12: READ AB(IS),LS(IS),CW(IS),CE(IS):LS(13) = LS(13) + LS(IS): NEXT
2044  REM
2045  REM  AVERAGE MONTHLY STREAM FLOW
2046  REM
2050  DATA     17,19,14,3,2,2,2,2,2,2,3,5 :AG = 0
2060  FOR IM = 10 TO 17: READ FM(IM):AQ = AQ + FM(IM): NEXT
2070  FOR IM = 18 TO 11: READ FT:FM(17) = FM(17) + FT:AQ = AQ + FT: NEXT
```

```
2074  REM
2075  REM  STREAM BANK HEIGHTS AND OTHER PARAMETERS
2076  REM
2080 AQ = AQ / 12:FM(I7) = FM(I7) / I5: FOR IS = I0 TO I2:HB(IS) = AQ / CW(IS) * CB: NEXT :PI = 3.14159:F1 = 48:F2 = 12.84:F3 = PI /
 F1:F4 = 36:F6 = 15:F9 = 99
2084  REM
2085  REM  SET UP YEARLY TEMPERATURE STREAM
2086  REM
2090  FOR IM = I0 TO I6: FOR IW = I0 TO I1:HT = (IM * I4) + (IW * I2) + F2:TB(IM,IW) = 10 + 60 *  SIN (HT * F3): NEXT : NEXT
2100 IM = I7:FW = IM * I4 + F2:FT = 0: FOR IW = I0 TO 20:HT = FW + IW:HT = HT - F1 * (HT > F1):FT = FT +  SIN (HT * F3): NEXT :TB(IM
,I0) = (10 + 60 * FT) / 20
2104  REM
2105  REM  SET UP YEARLY PRECIPITATION STREAM ONLY IF PATTERN IS TO BE SAME EVERY YEAR
2106  REM
2110  IF  NOT (HP) THEN  GOSUB 2130
2120  GOTO 2220
2124  REM
2125  REM  YEARLY PRECIPITAT
2126  REM
2130  FOR HM = I0 TO I6: FOR HW = I0 TO I1:RB(HM,HW) = I0: NEXT : FOR HW = I0 TO I3:HT = HM * I4 + HW + F2:FT =  RND (1):RR =  SIN (
HT * F3) * 0.72:FW = (HW > I1)
2140  IF FT < RR THEN  GOTO 2160
2150 RB(HM,FW) =  RND (1) * 0.5 + 0.1 + RB(HM,FW)
2160  NEXT : NEXT
2170 HM = 7:FW = IM * I4 + F2: FOR HW = I0 TO 20:HT = FW + HW:HT = HT - F1 * (HT > F1)
2180 FT =  RND (1):RR =  SIN (HT * F3) * 0.72: IF FT < RR THEN  GOTO 2200
2190 RB(HM,I0) = RB(HM,I0) + ( RND (1) * 0.5 + 0.1)
2200  NEXT
2210  RETURN
2220 EP = 800:EL = 50000:CS = 500:CU = 15:GM = 454:CA = 0:EW = 0.75:KG = 1E3
2224  REM
2225  REM  NUMBER OF FISH, FISH WEIGHT, AGE-SPECIFIC NATURAL SURVIVAL RATES
2226  REM
2230  DATA    1028,0.75 ,0.45,230,17.5,0.45
2240  DATA  57, 71,0.45,34,135.5,0.02
2250  FOR IA = I0 TO I3: READ FA(IA),FW(IA,I0),FS(IA): NEXT
2254  REM
2255  REM  SLP POINTS FOR FISH GROWTH AND SURVIVAL
2256  REM
2260  DATA    5,0,.25,25,.3,50,.6,75,1,100,.8
2270  DATA    3,0,0,6,1,36,1
2280  DATA    4,10,4,50,.2,227,.5,1360,0
2290  FOR I = I0 TO I2: READ NN(I): FOR J = I0 TO NN(I) - I1: READ XX(J,I),YY(J,I): NEXT : NEXT
2994  REM
2995  REM  VEGETATION/WILDLIFE MODEL DATA. READ IN MAXIMUM PLANT GROWTH RATES
2996  REM
3000  FOR IV = I0 TO I5: READ MG(IV):MG(IV) = MG(IV) * 2: NEXT
3010  DATA .75,.75,.75,.75,.38,.38
3014  REM
3015  REM  FORAGE MORTALITY RATES
3016  REM
3020  FOR IV = I0 TO I5: READ ML(IV):ML(IV) = ML(IV) * 20: NEXT
3030  DATA .05,.025,.025,.025,.05,.05
3034  REM
3035  REM  OPTIMAL EVAPOTRANSPIRATION RATES
3036  REM
3040  FOR IY = I0 TO I3: FOR IZ = I0 TO I7: READ ET(IY,IZ):ET(IY,IZ) = ET(IY,IZ) / 2.06: NEXT : NEXT
3050  DATA    .05,.25,.5,.5,.4,.3,.15,.15
3060  DATA    .07,.33,.67,.67,.53,.4,.2,.2
3070  DATA    .04,.2,.4,.4,.32,.24,.12,.12
3080  DATA    .02,.1,.2,.2,.08,.12,.06,.06
3084  REM
3085  REM  APPLIED SURFACE WATER TOLERANCES
3086  REM
3090  FOR IZ = I0 TO I3: READ RWT(IZ): NEXT
3100  DATA  1,1,1,1
```

```
3110  FOR IZ = I3 TO I9: READ NN(IZ): NEXT
3120  DATA    4,3,3,3,2,4,3
3124  REM
3125  REM  SLP POINTS FOR POTENTIAL NUMBER OF WILDLIFE SPECIES
3126  REM
3130  FOR IZ = I0 TO NN(3) - 1: READ XX(IZ,I3),YY(IZ,3): NEXT
3140  DATA   9,0,10,3,30,12,90,3
3144  REM
3145  REM  SLP POINTS FOR CALCULATING GRASS/SHRUB VIGOR
3146  REM
3150  FOR IZ = I0 TO NN(4) - 1: READ XX(IZ,I4),YY(IZ,I4): NEXT
3160  DATA   0,1,70,I,100,0
3164  REM
3165  REM  SLP POINTS FOR CALCULATING TEMPERATURE MODIFIER
3166  REM
3170  FOR IZ = I0 TO NN(5) - 1: READ XX(IZ,I5),YY(IZ,I5): NEXT
3180  DATA   40,0,80,I,100,.8
3184  REM
3185  REM  SLP POINTS FOR CALCULATING LEGUME FERTILIZATION MODIFIER
3186  REM
3190  FOR IZ = I0 TO NN(6) - 1: READ XX(IZ,I6),YY(IZ,I6): NEXT
3200  DATA 0,1,45,1,140,0
3204  REM
3205  REM  SLP POINTS FOR CALCULATING OTHER FORAGE FERTILIZATION MODIFIER
3206  REM
3210  FOR IZ = I0 TO NN(7) - 1: READ XX(IZ,I7),YY(IZ,I7): NEXT
3220  DATA  0,0,120,1
3224  REM
3225  REM  SLP POINTS FOR CALCULATING LEGUME PLANT VIGOR FACTOR
3226  REM
3230  FOR IZ = I0 TO NN(8) - I: READ XX(IZ,I8),YY(IZ,I8): NEXT
3240  DATA   0,1,40,.8,65,.5,100,0
3244  REM
3245  REM  SLP POINTS FOR CALCULATIN SEDGES AND RUSHES PLANT VIGOR FACTOR
3246  REM
3250  FOR IZ = I0 TO NN(9) - 1: READ XX(IZ,I9),YY(IZ,I9): NEXT
3260  DATA 0,1,85,1,100,0
3264  REM
3265  REM  MINIMUM FORAGE BIOMASS
3266  REM
3270 MX = 5000: FOR IV = I0 TO I5: READ WV(IV): NEXT
3280  DATA .1,1.,1.,1.,.1,.1
3284  REM
3285  REM  POINTERS WHICH MAP FORAGE TYPES INTO FORAGE CLASSES FOR GROWTH CALCULATIONS
3286  REM
3290  FOR IV = I0 TO I5: READ WC(IV): NEXT
3300  DATA  0,1,2,2,1,3
3310  FOR IV = I0 TO I5: READ P3(IV): NEXT
3320  DATA 0,1,I,1,2,2
3324  REM
3325  REM  PARAMETERS DESCRIBING PROTEIN CONTENT RELATIONSHIPS
3326  REM
3330  FOR I = I0 TO I2: READ C1(I),C2(I): NEXT
3340  DATA .221,.163,.139,.138,.0833,.128
3344  REM
3345  REM  HALF-SATURATION VALUES FOR CURVES RELATING COVER TO FORAGE BIOMASS
3346  REM
3350 SI(I0) = 700:SI(I1) = 2000
3360 P3 = PI / 2
3370  FOR IS = I0 TO I2:SF(IS) = 50: FOR I = I0 TO I1:PS(I,IS) = 50: NEXT : NEXT
3380 VC = .9
3384  REM
3385  REM  POINTERS FOR MAPPING FORAGE TYPES INTO CLASSES FOR SAVING AS INDICATORS
3386  REM
3390  FOR IV = I0 TO I5: READ CC(IV): NEXT
3400  DATA  0,1,2,2,3,3
```

```
3404  REM
3405  REM  WINTER MORTALITY RATES
3406  REM
3410  FOR IV = I0 TO I5: READ BM(IV): NEXT
3420  DATA  .7,.8,.5,.5,.1,.1
3424  REM
3425  REM  INITIAL PLANT BIOMASS
3426  REM
3430  FOR IS = I0 TO I2: FOR IV = I0 TO I5: READ BA(IV,IS,I0):BA(IV,IS,IR) = BA(IV,IS,I0) * (1 - BM(IV)):BA(IV,IS,I1) = BA(IV,IS,I0)

3440 PV(IV,IS,IR) = I1:MB(IV,IS,I0) = BA(IV,IS,I0) * I2:MB(IV,IS,I1) = MB(IV,IS,I0): NEXT : NEXT
3450  DATA    10.2,13.1,524.2,436.2,189.3,436.3,16,240,1800,3300,64.5,4613,52,1000,1000,1500,50,300
3460  FOR IR = I0 TO I1: FOR IS = I0 TO I2: FOR IV = I0 TO I5:D1(IV,IS,IR) = BA(IV,IS,IR): NEXT : NEXT : NEXT
3464  REM
3465  REM  OPTIMUM DEPTH OF WATER TABLE FOR FORAGE TYPES
3466  REM
3470  FOR IV = I0 TO I5: READ OD(IV): NEXT
3480  DATA -2,-.5,-2.5,-2.5,-3,-3
3484  REM
3485  REM  RANGE OF TOLERABLE WATER TABLE DEPTHS ABOVE AND BELOW OPTIMUM
3486  REM
3490  FOR I = I0 TO I1: FOR IV = I0 TO I5: READ RD(IV,I): NEXT : NEXT
3500  DATA -5,-2.5,-6,-6,-6,-1E6
3510  DATA .1,1,.1,.1,-1.5,-1.5
3994  REM
3995 C AT TLE / EC ON OMICS DATA , READ IN FIRST TIME STEP IN WHICH CATTLE ARE ON EACH SPATIAL UNIT
3996  REM
4000  FOR IS = 10 TO 11: FOR DU = I0 TO I5: READ DB(DU,IS): NEXT : NEXT
4010  DATA    5, 7, 5, 7, 5, 7,4,5,99,4,5,99
4014  REM
4015  REM  LAST TIME STEP IN WHICH CATTLE ARE ON EACH SPATIAL UNIT
4016  REM
4020  FOR IS = I0 TO I1: FOR DU = I0 TO I5: READ DE(DU,IS): NEXT : NEXT
4030  DATA     7, 9, 7, 9, 7, 9, 4,5,99,4,5,99
4040 YC = 1200:AU = 400:EX(0) = .95:EX(1) = .5:DF = .33:EA = .55:SC = .6:BV = .76
4044  REM
4045  REM SLP POINTS FOR CALCULATING FORAGE PREFERENCE FACTORS OVER THE YEAR
4046  REM
4050  FOR I = I0 TO I4: FOR NS = 13 TO 18: READ XX(I,NS),YY(I,NS): NEXT : NEXT
4060  DATA   1,.4,1,.3,1,.25,1,.04,1,.01,1,0
4070  DATA   4,.5,4,.25,4,.2,4,.02,4,.03,4,0
4080  DATA    5,.5, 5,.4, 5,.05, 5,.04, 5,.01, 5,0
4090  DATA     8,.5, 8,.25, 8,.2, 8,.04, 8,.01, 8,0
4100  DATA    11,.3,11,.5,11,.15,11,.01,11,.01,11,0
4104  REM
4105  REM  CALCULATE FORAGE PREFERENCE FACTORS. DONE ONCE ONLY HERE TO SAVE EXECUTION TIME
4106  REM
4110  FOR NS = 13 TO 18:NN(NS) = I5: FOR IT = I0 TO I4:XS = IT * 20: GOSUB 20000
4120 PF(IT,NS - 13) = SL: NEXT : NEXT
4124  REM
4125  REM SLP POINTS FOR CALCULATING FORAGE DEMAND MULTIPLIER
4126  REM
4130  FOR I = I0 TO I1: READ XX(I,11),YY(I,11): NEXT :NN(11) = 2
4140  DATA   8,.315, 9,.415
4144  REM
4145  REM  SLP POINTS FOR CALCULATING CATTLE RIPARIAN USE FACTOR
4146  REM
4150  FOR I = I0 TO I2: READ XX(I,12),YY(I,12): NEXT :NN(12) = 3
4160  DATA  0,1.3, 5,1.38, 7,1.66
4170 B1 = .4:B2 = 1.33:WN = 350:ZD = 1E - 6
4174  REM  PROPORTION OF EACH FORAGE TYPE WHICH CATTLE CAN CONSUME
4175  REM
4180  FOR IV = I0 TO I5: READ DG(IV): NEXT
4190  DATA 1,.5,1,.3,.1,.1
4200 EZ = 13
9994  REM
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9995  REM  AREAS OF EACH OF THE 6 LAND PARCELS (RIPARIAN/NON-RIPARIAN IN 3 SPATIAL UNITS)
9996  REM
10000  FOR IR = I0 TO I1: FOR IS = I0 TO I2: READ AP(IS,IR): NEXT : NEXT
10010  DATA  339,22,912,9563,798.1779
10014  REM
10015  REM  TOTAL SPATIAL UNIT AREAS
10016  REM
10020  FOR IS = I0 TO I2: READ AS(IS): NEXT
10030  DATA 9902,820,2691
10034  REM
10035  REM  PROPORTION OF TOTAL SPATIAL UNIT AREA IN RIPARIAN/NON-RIPARIAN PARCEL
10036  REM
10040  FOR IR = I0 TO I1: FOR IS = I0 TO I2: READ AP(IS,IR): NEXT : NEXT
10050  DATA .0342,.0269,.339,.9658,.9731,.661
10054  REM
10055  REM  TIME STEPS IN WHICH TO SAVE INDICATORS
10056  REM
10060  FOR I = I0 TO I3: READ SW(I): NEXT
10070  DATA  8,8,14,14
10080  RESTORE
10090  PRINT "ENTER COMMANDS, THEN CONT": END
10094  REM
10095  REM  LOAD MODEL AND BEGIN EXECUTING
10096  REM
10100  PRINT  CHR$ (4);"BLOAD CHAIN,A520": CALL 520"MODEL"
19994  REM
19995  REM  SLP FUNCTION
19996  REM
20000 XN = NN(NSLP)
20010 SLP = YY(0.NSLP): IF XS <  = XX(0,NS) THEN  RETURN
20020 SLP = YY(XN - 1,NS): IF XS >  = XX(XN - 1,NS) THEN  RETURN
20030 XM = XN - 2
20040 I = 0
20050  IF XS > XX(I + 1,NS) THEN  GOTO 20090
20060 SLP = (YY(I + 1,NS) - YY(I,NS)) / (XX(I + 1,NS) - XX(I,NS))
20070 SLF = SLP * (XS - XX(I,NS)) + YY(I,NS)
20080  RETURN
20090 I = I + I1: IF I <  = XM GOTO 20050
20100 SLP = YY((XN - 1),NS)
20110  RETURN

]
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FILE: MODEL DOC

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]LIST

4  REM
5  REM  SKIP OVER SOME HYDROLOGY SUBROUTINES
6  REM
10  GOTO 110
14  REM
15  REM  CALLED FOR YEAR TO YEAR VARIATION IN RAINFALL
16  REM
20  FOR HM = I0 TO I6: FOR HW = I0 TO I1:RB(HM,HW) = I0: NEXT : FOR HW = I0 TO I3:HT = HM * I4 + HW + F2:FT =  RND (1):RR =  SIN (HT
 * F3) * 0.72:FW = (HW > I1)
30  IF FT < RR THEN  GOTO 50: REM  MOD
40 RB(HM,FW) =  RND (1) * 0.5 + 0.1 + RB(HM,FW)
50  NEXT : NEXT
54  REM
55  REM  THIS SECTION HANDLES RAINFALL N THE LONG OVERWINTER TIME STEP
60 HM = 7:FW = IM * I4 + F2:RB(HM,I0) = I0:RB(HM,I1) = I0: FOR HW = I0 TO 20:HT = FW + HW:HT = HT - F1 * (HT > F1)
70 FT =  RND (1):RR =  SIN (HT * F3) * 0.72: IF FT < RR THEN  GOTO 90
80 RB(HM,I0) = RB(HM,I0) + ( RND (1) * 0.5 + 0.1)
90  NEXT
100  RETURN
110  HOME : VTAB 10: PRINT "MODEL EXECUTING, PLEASE WAIT....."
114  REM
115  REM  THIS IS THE BEGINNING OF THE TIME LOOP
116  REM
120  FOR TI = ZS TO NT
130 IT = 0
134  REM
135  REM  CALCULATE THE YEAR OF THE SAVAL ROTATION (DU)
136  REM
140 DU = TI - I6 * ( INT (TI / I6)):AA = 0:FD(I2,I1) = I1
150  FOR IS = I0 TO I1
154  REM
155  REM  GET THE LAST WEEK OF CATTLE GRAZING
156  REM
160 FD(IS,I0) = DE(DU,IS):FD(IS,I1) = I1: IF FD(IS,I0) = F9 THEN FD(IS,I0) = FD(I2,I0)
170  NEXT
174  REM
175  REM  BEGIN THE MONTH AND WEEK TIME STEP LOOPS
176  REM
180  FOR IM = I0 TO I7:IL = (IM = I7): FOR IW = I0 TO I1 - IL
184  REM
185  REM  CALCULATE THE TIME STEP WITHIN THE YEAR (IT)
186  REM
190 IT = I2 * IM + IW
194  REM
195  REM  PRINT OUT INFORMATION TO TELL THE USER THE CURRENT TIME STEP
196  REM
200  IF SA = 2 AND IM = I0 AND IW = I0 THEN  VTAB 15: POKE 36,NT + 1 - TI: PRINT "."
210  IF SA = 1 THEN  VTAB 15: POKE 36,I4 - IT: PRINT "."
214  REM
215  REM  ZERO OUT CUMULATIVE FORAGE PRODUCTION IN THE FIRST TIME STEP
216  REM
220  IF IT = I0 THEN  FOR IR = I0 TO 11: FOR IS = I0 TO I2: FOR IV = I0 TO I5:PB(IV,IS,IR) = I0: NEXT : NEXT : NEXT
224  REM
225  REM  CALL THE HYDROLOGY MODEL N THE FIRST WEEK OF EACH MONTH ONLY
226  REM
230  IF IW = 0 THEN : IF MS(I0) THEN  GOSUB 2000
234  REM
235  REM  CALL THE VEGETATION/WILDLIFE MODEL
236  REM
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240  IF MS(I1) THEN  GOSUB 4000
244  REM
245  REM  CALCULATE AVERAGE STREAM BANK SHADING
246  REM
250  FOR IS = I0 TO I2: IF (FD(IS,I0) >  = IT) AND (FD(IS,I1)) THEN AA = AA + PS(I1,IS) * LS(IS):FD(IS,I1) = I0
260  NEXT
264  REM
265  REM  CALL THE FISHERIES MODEL IN THE LAST TIME STEP OF THE YEAR ONLY
266  REM
270  IF IL THEN : IF MS(I2) THEN  GOSUB 2180
274  REM
275  REM  CALL THE CATTLE/ECONOMICS MODEL
276  REM
280  IF MS(I3) THEN  GOSUB 6000
284  REM
285  REM  CHECK WHICH ELEMENT OF THE OUTPUT ARRAY INDICATORS SHOULD BE STORED
286  REM
290 NI = TI: IF SA = I1 THEN NI = IT
300  IF SA = I2 AND IM * I2 + IW <  > SW(I0) THEN  GOTO 320
304  REM
305  REM  SAVE STREAM WIDTHS
306  REM
310  FOR IS = I0 TO I2:Z(IS,NI) = CW(IS): NEXT
314  REM
315  REM  SAVE WATER TABLE DEPTHS
316  REM
320  FOR IS = I0 TO I2:Z(40 + IS,NI) = WD(IS): NEXT
330  IF SA = I2 AND IM * I2 + IW <  > SW(I3) THEN  GOTO 390
334  REM
335  REM  SAVE FISHERIES INDICATORS
336  REM
340 FT = 0: FOR IA = I0 TO I3:Z(I3 + IA,NI) = FA(IA):FT = FT + FA(IA) * FW(IA,I0): NEXT :Z(I9,NI) = FT / KG
350  FOR IA = I2 TO I3:Z(I5 + IA,NI) = FW(IA,I0): NEXT
360 Z(11,NI) = FQ:Z(J1,NI) = CT
364  REM
365  REM  SAVE TEMPERATURE, RAINFALL INDICATORS
366  REM
370 Z(38,NI) = TE(IW):Z(39,NI) = RR(IW)
390  IF SA = I2 AND IM * I2 + IW <  > SW(I1) THEN  GOTO 410
394  REM
395  REM  SAVE VEGETATION/WILDLIFE INDICATORS
396  REM
400  FOR IS = I0 TO I2:Z(24 + IS,NI) = WB(IS):Z(27 + IS,NI) = PS(I0,IS): FOR IV = I0 TO I5:WC = WC(IV):PO = 12 + IS * I4 + WC:Z(PO,N
I) = Z(PO,NI) + P8(IV,IS,I0): NEXT : NEXT :Z(30,NI) = EH / 2000
410  IF SA = I2 AND IM * I2 + IW <  > SW(I2) THEN  GOTO 430
414  REM
415  REM  SAVE CATTLE/ECONOMIC INDICATORS
416  REM
420 Z(31,NI) = DC(0):Z(32,NI) = DC(1):Z(33,NI) = CD(0):Z(34,NI) = CD(1):Z(35,NI) = WA:Z(36,NI) = SS:Z(37,NI) = EY / 2000
424  REM
425  REM  END WEEK LOOP
426  REM
430  NEXT IW
434  REM
435  REM  END MONTH LOOP
436  REM
440  NEXT IM
444  REM
445  REM  END YEAR LOOP
446  REM
450  NEXT TI
460  IF SA = 1 THEN NT = 14
464  REM
465  REM  LOAD IN GRAPHICS
466  REM
470  GOTO 10000
```

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1994  REM
1995  REM  BEGINNING OF HYDROLOGY MODEL. CALCULATE RAINFALL FOR MONTH
1996  REM
2000  IF IT = 10 THEN AQ = 0: IF HF THEN  GOSUB 20
2020 RR(I0) = RB(IM,I0):RR(I1) = RB(IM,I1)
2024  REM
2025  REM  CALCULATE TEMPERATURE FOR MONTH
2026  REM
2030  FOR HW = I0 TO I1 - IL
2040 ZR = I0: IF HR THEN  GOSUB 12000
2050 TE(HW) = TB(IM,HW) *  EXP (ZR * HV * (I1 - 0.08 * IL))
2060  NEXT
2064  REM
2065  REM  BANK STABILITY FACTOR IS A FUNCTION OF TIME OF YEAR
2066  REM
2070 BS = .3
2080  IF IT < 11 THEN BS = 0.5
2090  IF IT < 4 THEN BS = 1
2094  REM
2095  REM  CALCULATE CHANNEL WIDTH AS A FUNCTION OF CATTLE USE
2096  REM
2100 DT = 0:WD = 0: FOR IS = I0 TO I2
2110 CZ = (I1 - 0.009 * SF(IS)) * CM(IS) * EC:CZ = (CZ / HB(IS)) * BS * BE
2116  REM
2120 FW = CW(IS):CW(IS) = FW + FW * MR * (I1 - FW / CE(IS)) + CZ
2124  REM
2125  REM  BANK HEIGHT
2126  REM
2130 HB(IS) = HB(IS) * FW / CW(IS)
2134  REM
2135  REM  FLOW DEPTH
2136  REM
2140 DQ = FM(IM) / CW(IS) * IN:DT = DT + DQ:WD(IS) = HB(IS) - DQ / IN:WD = WD + WD(IS)
2150  NEXT
2154  REM
2155  REM  AVERAGE YEARLY FLOW
2156  REM
2160 FT = I4 * IL:AQ = ((IM * AQ) + ((DT / I3) * (I1 + FT))) / (I1 + IM + FT)
2170  RETURN
2174  REM
2175  REM  FISHERIES MODEL. CALCULATE AVERAGE BANK SHADING
2176  REM
2180 AA = AA / LS(I3)
2194  REM
2195  REM  SURVIVAL RATE FROM BANK SHADING
2196  REM
2200 NS = I0:XS = AA: GOSUB 20000:AV = SL
2204  REM
2205  REM  SURVIVAL RATE AS A FUNCTION OF FLOW DEPTH
2206  REM
2210 NS = I1:XS = AQ: GOSUB 20000:AD = SL
2214  REM
2215  REM  NUMBER OF EGGS LAID PER MILE
2220 EN = FW(I3,I0) / GM * FA(I3) * EP: IF EN > EL THEN EN = EL
2230 EN = EN * AV * AD * FS(I0)
2234  REM
2235  REM  FISH HARVEST
2236  REM
2240  GOSUB 2350
2244  REM
2245  REM  FISH SURVIVAL
2246  REM
2250  GOSUB 2290
2254  REM
2255  REM  AGE THE FISH POPULATION
2256  REM
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2260  GOSUB 2490
2270 FQ = AQ
2280  RETURN
2290 FT = AV * AD
2294  REM
2295  REM  REMOVE FISH WHICH DO NOT SURVIVE
2296  REM
2300  FOR IA = I0 TO I3
2310 FA(IA) = FA(IA) * FT * FS(IA)
2320 NS = I2:XS = FW(IA,I0): GOSUB 20000:GP = SL
2324  REM
2325  REM
2330 FW(IA,I0) = FW(IA,I0) + FW(IA,I0) * AV * GP * I4
2340  NEXT : RETURN
2350 FT = 0:CT = I0:CV = I0
2360  FOR IA = I0 TO I3:FW(IA,I1) = I1
2364  REM
2365  REM  CALCULATE # FISH VULNERABLE TO FISHING
2366  REM
2370  IF ((FW(IA,I0) / I3) ^ 0.5) > I6 THEN FT = FT + FA(IA):FW(IA,I1) = I0
2380  NEXT
2390  IF FT < I1 THEN  RETURN
2400 CR = FT / CS
2404  REM
2405  REM  CALCULATE FISHING EFFORT
2406  REM
2410 CV = F6 + F6 * CR
2414  REM
2415  REM  FISH HARVEST
2416  REM
2420 CT = CR * CV * I3
2424  REM
2425  REM  AGE THE POPULATION
2426  REM
2430  FOR IA = I0 TO I3
2440  IF FW(IA,I1) THEN  GOTO 2470
2450 HT = CT * (FA(IA) / FT)
2460 FA(IA) = FA(IA) - HT
2470  NEXT
2480  RETURN
2484  REM
2485  REM  UPDATE WEIGHT OF OLDEST AGE CLASS
2486  REM
2490 FW(I3,I0) = (FW(I3,I0) * FA(I3) + FW(I2,I0) * FA(I2)) / (FA(I3) + FA(I2) + ZD)
2494  REM
2495  REM  UPDATE FISH NUMBERS IN OLDEST AGE CLASS
2496  REM
2500 FA(I3) = FA(I3) + FA(I2)
2510 IA = I3
2520  FOR IU = I1 TO I2:IA = IA - I1:FT = IA - I1
2524  REM
2530 FA(IA) = FA(FT)
2534  REM
2535  REM  UPDATE THE WEIGHTS
2536  REM
2540 FW(IA,I0) = FW(FT,I0)
2544  REM
2545  REM  ADD FISH BORN INTO YOUNGEST AGE CLASS
2546  REM
2550  NEXT :FA(I0) = EN:FW(I0,I0) = EW
2560  RETURN
3994  REM
3995  REM  VEGETATION/WILDLIFE SUBMODEL
3996  REM
4000  IF IM = I7 THEN  GOTO 4340
4004  REM
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4005  REM  CALCULATE TEMPERATURE MODIFIER ON PLANT GROWTH AND TOTAL SURFACE WATER
4006  REM
4010 NS = I5:XS = TE(IN): GOSUB 20000:TM = SL: FOR IS = I0 TO I2: FOR I = I0 TO I1:PS(I,IS) = I0: NEXT : FOR IR = I0 TO I1:LI = RR(I
W) + IR(IS,IR)
4014  REM
4015  REM  CALCULATE FERTILIZER MODIFIER ON VEGETATION GROWTH
4016  REM
4020 F1(I0) = I1:F1(I1) = I0
4030  IF UF(IS,IR) = I0 THEN  GOTO 4050
4040  FOR NS = 6 TO 7:XS = UF(IS,IR): GOSUB 20000:F1(NS - I6) = SL
4044  REM
4045  REM  LOOP OVER VEGETATION TYPES
4046  REM
4050  FOR IV = I0 TO I5
4054  REM
4055  REM  DETERMINE WHICH FERTILIZER MODIFIER CURVE TO USE FOR GIVEN FORAGE TYPE
4060 V3 = IV > I0
4064  REM
4065  REM  WATER TABLE MODIFIER
4066  REM
4070 IC =  - WD(IS) > OD(IV):WTF = I0: IF  ABS (WD(IS)) >  ABS (RD(IV,IC)) THEN  GOTO 4090
4080 WTF =  COS (( - WD(IS) - OD(IV)) / RD(IV,IC) * P3)
4090 WC = WC(IV)
4094  REM
4095  REM  SURFACE WATER APPLIED MODIFIER
4096  REM
4100 PW =  ABS (LI - ET(WC,IM)): IF PW > RWT(WC) THEN PWWF = 0: GOTO 4120
4110 XX = PW / RWT(WC):PWWF =  COS (XX * P3)
4114  REM
4115  REM  UPDATE CUMULATIVE FORAGE CONSUMPTION BY CATTLE
4116  REM
4120 CB(IV,IS,IR) = CB(IV,IS,IR) + RP(IV,IS,IR)
4124  REM
4125  REM  GROW THE FORAGE
4126  REM
4130 PG(IV) = MG(IV) * (PWWF + WTF + TM + F1(V3) + PV(IV,IS,IR)) / I5:BA(IV,IS,IR) = (BA(IV,IS,IR) - RP(IV,IS,IR)) * (1 + PG(IV) - 
L(IV)):P8 = BA(IV,IS,IR) - DI(IV,IS,IR): IF SA = I1 THEN PB(IV,IS,IR) = P8
4131  IF SA = 2 AND IT < SW(I1) + 1 THEN PB(IV,IS,IR) = PB(IV,IS,IR) + P8
4134  REM
4135  REM  SET LOWER LIMIT TO FORAGE BIOMASS IF NECESSARY
4136  REM
4140  IF BA(IV,IS,IR) < WV(IV) THEN BA(IV,IS,IR) = WV(IV)
4144  REM
4145  REM  SET UPPER LIMIT TO FORAGE BIOMASS IF NECESSARY
4146  REM
4150  IF BA(IV,IS,IR) > MB(IV,IS,IR) THEN BA(IV,IS,IR) = MB(IV,IS,IR)
4154  REM
4155  REM  GET NET CHANGE IN BIOMASS OVER LAST TIME STEP
4156  REM
4160 DI = BA(IV,IS,IR) - DI(IV,IS,IR)
4170  IF RP(IV,IS,IR) < 0 OR DI < I0 THEN  GOTO 4190
4174  REM
4175  REM  SUM TOTAL FORAGE CONSUMPTION
4176  REM
4180 PB(IV,IS,IR) = PB(IV,IS,IR) + DI
4184  REM
4185  REM  KEEP TRACK OF PRESENT BIOMASS FOR FUTURE TIME STEP
4186  REM
4190 DI(IV,IS,IR) = BA(IV,IS,IR)
4194  REM
4195  REM  ONLY DO COVER AND WILDLIFE CALCULATIONS IN RIPARIAN ZONE
4196  REM
4200  IF IR = I1 THEN  GOTO 4220
4204  REM
4205  REM  SUM FORAGE BIOMASS INTO HERBACEOUS AND SHRUB CATEGORIES
4206  REM
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4210 VS = IV > I3:PS(VS,IS) = PS(VS,IS) + BA(IV,IS,IR)
4220  NEXT
4224  REM
4225  REM  CALCULATE HERBACEOUS AND SHRUB COVER IN RIPARIAN ZONE
4226  REM
4230  IF IR = I1 THEN  GOTO 4260
4240 SF(IS) = I0: FOR I = I0 TO I1:PS(I,IS) = 100 * PS(I,IS) / (S1(I) + PS(I,IS)):SF(IS) = SF(IS) + PS(I,IS): NEXT : IF SF(IS) > 100
THEN SF(IS) = 100
4244  REM
4245  REM  DETERMINE NUMBER OF BIRD SPECIES IN RIPARIAN
4246  REM
4250 NS = I3:XS = PS(I1,IS): GOSUB 20000:WB(IS) = SL
4260  NEXT
4270  NEXT
4274  REM
4275  REM  HAYING OCCURS ON AUGUST 1 ONLY
4276  REM
4280  IF IT <  > I8 THEN  GOTO 4330
4284  REM
4285  REM  HAY PRODUCTION IS FROM NON-SHRUB FORAGE TYPES IN HAY MEADOW RIPARIAN ONLY
4286  REM
4290 EH = I0:GP = I0: FOR IV = I0 TO I3:CH = BA(IV,I2,I0) * VC:X = P3(IV):WP = C1(X) *  EXP ( - C2(X) * IT):EH = EH + CH * AR(I2,I0)

4300 GP = GP + WP * CH * AR(I2,I0):BA(IV,I2,I0) = BA(IV,I2,I0) - CH
4310  NEXT
4314  REM
4315  REM  TP IS AVERAGE PROTEIN CONTENT OF HAY
4316  REM
4320 GP = GP / (EH + ZD)
4324  REM
4325  REM  CALCULATE PLANT VIGOR FACTOR AT THE END OF THE YEAR ONLY
4326  REM
4330  IF IT < 14 THEN  RETURN
4340  FOR IR = I0 TO I1: FOR IS = I0 TO I2: FOR IV = I0 TO I5
4344  REM
4345  REM  CALCULATE PROPORTION OF TOTAL PRODUCTION WHICH IS CONSUMED
4346  REM
4350 XX = CB(IV,IS,IR) / (PB(IV,IS,IR) + ZD)
4354  REM
4355  REM  RETAIN THE LAST 3 YEARS OF PROPORTION OF FORAGE PRODUCTION CONSUMED
4356  REM
4360 UT(IV,IS,IR,I0) = UT(IV,IS,IR,I1):UT(IV,IS,IR,I1) = UT(IV,IS,IR,I2)
4370 UT(IV,IS,IR,I2) = 100 * XX
4374  REM
4375  REM  CALCULATE AVERAGE PROPORTION FORAGE CONSUMED IN LAST 3 YEARS
4376  REM
4380 XX = (UT(IV,IS,IR,I0) + UT(IV,IS,IR,I1) + UT(IV,IS,IR,I2)) / 3
4384  REM
4385  REM  CALCULATE PLANT VIGOR FACTOR. THE RELATIONSHIP VARIES WITH FORAGE TYPE
4386  REM
4390  IF IV = I0 THEN NS = 8
4400  IF IV = I1 THEN NS = 9
4410  IF IV > I1 THEN NS = 4
4420 XS = XX
4430  GOSUB 20000
4440 PV(IV,IS,IR) = SLP
4444  REM
4445  REM  WINTER FORAGE LOSS
4446  REM
4450 BA(IV,IS,IR) = BA(IV,IS,IR) * (1. - BM(IV))
4460 CB(IV,IS,IR) = I0:PB(IV,IS,IR) = I0
4464  REM
4465  REM  END OF VEGETATION TYPE, SPATIAL UNIT, RIPARIAN/NON-RIPARIAN LOOPS
4466  REM
4470  NEXT IV: NEXT IS: NEXT IR
4480  RETURN
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```
5994  REM
5995  REM  CATTLE/ECONOMICS SUBMODEL
5996  REM
6000  IF TI > 0 OR IT > 0 THEN  GOTO 6020
6010 TS = 0:TD = 0
6014  REM
6015  REM  ZERO OUT VARIABLES AT THE START OF EACH TIME STEP
6016  REM
6020 PR = 0:XE = 0: FOR IV = I0 TO I5: FOR IS = I0 TO I2: FOR IR = I0 TO I1:RP(IV,IS,IR) = I0: NEXT : NEXT : NEXT :DC(I0) = I0:DC(I1
) = I0:CD(I0) = I0:CD(I1) = I0
6024  REM
6025  REM  IN FINAL TIME STEP, ONLY INDICATORS ARE CALCULATED
6026  REM
6030  IF IM = I7 GOTO 6200
6040  FOR IS = I0 TO I1
6044  REM
6045  REM  CHECK THAT CATTLE ARE SUPPOSED TO BE ON PARTICULAR PASTURE IN GIVEN WEEK
6046  REM
6050  IF IT < DB(DU,IS) OR IT > DE(DU,IS) GOTO 6180
6054  REM
6055  REM  CALCULATE CATTLE FORAGE DEMAND
6056  REM
6060 NS = 11:XS = IT: GOSUB 20000
6070 UC = SL:PR = YC * UC * AU:P1 = PR:XE = PR
6074  REM
6075  REM  CALCULATE PROTEIN CONTENT OF FORAGE
6076  REM
6080  FOR IV = I0 TO I5:X = P3(IV):WP(IV) = C1(X) *  EXP ( - C2(X) * IT): NEXT
6084  REM
6085  REM  CONSUME THE FORAGE, FROM THE MOST PREFERRED DOWN TO LEAST PREFERRED
6086  REM
6090  FOR IR = I0 TO I1:DC(IR) = 0: IF IR = I1 THEN PR = XE
6094  REM
6095  REM  DON'T CONSUME ANY MORE FORAGE IF DEMANDS HAVE BEEN MET
6096  REM
6100  FOR IV = I0 TO I5: IF XE < ZD THEN  GOTO 6130
6104  REM
6105  REM  CHECK TO MAKE SURE CATTLE DON'T CONSUME MORE FORAGE THAN IS THERE
6106  REM
6110 EM = EX(IR) * BA(IV,IS,IR) * DS(IV) * AR(IS,IR):RP(IV,IS,IR) = PR * PF(IT,IV): IF RP(IV,IS,IR) > EM THEN RP(IV,IS,IR) = EM
6120 XE = XE - RP(IV,IS,IR):TS = TS + RP(IV,IS,IR):DC(IR) = DC(IR) + RP(IV,IS,IR):TD = TD + (B1 + B2 * WP(IV)) * RP(IV,IS,IR):RP(IV
IS,IR) = RP(IV,IS,IR) / AR(IS,IR)
6130  NEXT
6140  NEXT
6150 NS = 12: GOSUB 20000
6154  REM
6155  REM  CALCULATE CATTLE USE DAYS ON RIPARIAN ZONE
6156  REM
6160 UU = SL:CD(IS) = UU * .5 * YC * ((1 - OF) + (OF * DC(I0) / (DC(I0) + DC(I1) + ZD))):DC(I0) = DC(I0) * 100 / (P1 - XE + ZD):DC(I
1) = 100 * DC(I1) / (P1 - XE + ZD)
6170 CM(IS) = CM(IS) + (CD(IS) / AR(IS,I0)) * (AB(IS) / AR(IS,I0)) * AC * BC
6180  NEXT
6184  REM
6185  REM  SKIP OVER LAST PART OF MODEL IF NOT IN FINAL TIME STEP OF THE YEAR
6186  REM
6190  IF IT < 14 THEN  RETURN
6200 WA = WN * (TD / (TS + ZD)) / EA:SS = WA * SC * YC * BV:SB = (B1 + B2 * TP) * EH:SB = YC * AW * I4 * I7 * EZ - SB: IF SB < I0 TH
EN SB = I0
6204  REM
6205  REM  CALCULATE WEANING WEIGHT, REVENUE FROM CALF SALES, AND HAY NEEDED TO KEEP OVER WINTER
6206  REM
6210 EY = SB / (B1 + B2 * GP)
6214  REM
6215  REM  DETERMINE HAY WHICH MUST BE BOUGHT
6216  REM
6220  RETURN
```

```
9994  REM
9995  REM  CALL IN GRAPHICS AFTER MODEL FINISHED EXECUTING
9996  REM
10000 X =  FRE (0): PRINT  CHR$ (4);"BLOAD CHAIN, A520": CALL 520"GRAPHICS"
12000 XR =  RND (15):RZ = I2 * XR - I1:ZR =  LOG ((RZ + I1) / (I1 - RZ)) / 1.82: RETURN
19994  REM
19995  REM  LINEAR INTERPOLATION FUNCTION
19996  REM
20000 XN = NN(NSLP)
20010 SLP = YY(0,NSLP): IF XS <  = XX(0,NS) THEN  RETURN
20020 SLP = YY(XN - 1,NS): IF XS >  = XX(XN - 1,NS) THEN  RETURN
20030 XM = XN - 2
20040 I = 0
20050  IF XS > XX(I + 1,NS) THEN  GOTO 20090
20060 SLP = (YY(I + 1,NS) - YY(I,NS)) / (XX(I + 1,NS) - XX(I,NS))
20070 SLP = SLP * (XS - XX(I,NS)) + YY(I,NS)
20080  RETURN
20090 I = I + I1: IF I <  = XM GOTO 20050
20100 SLP = YY((XN - 1),NS)
20110  RETURN

]
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]LIST 1,59999

4  REM
5  REM  LOAD SHAPE TABLE AND CLEAR GRAPHICS SCREEN
6  REM
10  PRINT  CHR$ (4);"BLOAD SHAPE TABLE,A$800": POKE 232,0: POKE 233,08: HGR
20  SCALE= 1:ZX = 210:ZY = 110:ZW = 1:ZZ = 140:ZC = 3
24  REM
25  REM  DRAW THE GRAPHICS BOX
26  REM
30  CALL 62450: HCOLOR= 3: HPLOT ZW,ZZ - ZY TO ZW,ZZ TO ZW + ZX,ZZ TO ZW + ZX,ZZ - ZY TO ZW,ZZ - ZY: VTAB 24
:ZU = 0:YY =  - 7:AA = 24:BB = 150
34  REM
35  REM  CALL SUBROUTINE THAT PRINTS FIRST AND LAST TIME STEP ON X AXIS
36  REM
40  GOSUB 670
44  REM
45  REM  PRINT PROMPT AND WAIT FOR USER INPUT
46  REM
50  INPUT "PLOT VAR$";A$
54  REM
55  REM  PRINT PROMPT AGAIN IF INPUT IS A CARRIAGE RETURN
56  REM
60  IF  LEN (A$) = 0 THEN  GOTO 50
64  REM
65  REM  RERUN THE MODEL FROM THE BEGINNING
66  REM
70  IF A$ = "START" THEN  TEXT : PRINT  CHR$ (4);"RUN START"
74  REM
75  REM  END MODEL EXECUTION
76  REM
80  IF A$ = "STOP" THEN  TEXT : END
84  REM
85  REM  CALL SUBROUTINE WHICH PRINTS OUT MODEL INDICATOR DEFINITIONS
86  REM
90  IF A$ = "?" THEN  GOSUB 820: GOTO 50
94  REM
95  REM  CALL SUBROUTINE WHICH PRINTS GRAPHICS PAGE ON PRINTER
96  REM
100  IF  LEFT$ (A$,1) = "Q" THEN  GOSUB 490: GOTO 50
104  REM
105  REM  SAVE THE MODEL OUTPUT ARRAY IN A BINARY FILE
106  REM
110  IF  LEFT$ (A$,2) <  > "ZS" THEN  GOTO 130
120 X = 5 * (NV + 1) * (NT + 1) + 9:X$ =  STR$ (X):XX =  PEEK (106) * 256 +  PEEK (107):A$ =  RIGHT$ (A$, LE
N (A$) - 3): PRINT  CHR$ (4);"BSAVE ";A$;",A";XX;",L";X$: GOTO 50
124  REM
125  REM  LOAD A BIANNARY FILE INPUT THE MEMORY FOR MODEL OUTPUT ARRAY
126  REM
130  IF  LEFT$ (A$,2) <  > "ZL" THEN  GOTO 150
140 X =  PEEK (108) * 256 +  PEEK (107):A$ =  RIGHT$ (A$, LEN (A$) - 3): PRINT  CHR$ (4);"BLOAD ";A$;",A";X:
 GOTO 50
144  REM
145  REM  SAVE THE GRAPHICS IMAGE AS A BINARY FILE
146  REM
150  IF  LEFT$ (A$,1) <  > "S" THEN 190
160 A$ =  RIGHT$ (A$, LEN (A$) - 2)
170  PRINT  CHR$ (4);"BSAVE ";A$;",A8192,L812"
180  GOTO 50
184  REM
185  REM  LOAD A BINARY FILE INTO THE GRAPHICS PAGE
186  REM
190  IF  LEFT$ (A$,1) <  > "R" THEN  GOTO 230
200 A$ =  RIGHT$ (A$, LEN (A$) - 2)
210  PRINT  CHR$ (4);"BLOAD ";A$;",A8192"
220  GOTO 50
```

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224  REM
225  REM  CLEAR THE GRAPHICS SCREEN
226  REM
230  IF A$ = "G" THEN  GOTO 30
234  REM
235  REM  CWHEN THIS POINT IS REACHED THE INPUT SHOULD BE AN INDICATOR NUMBER
236  REM  CHECK THAT FIRST CHARACTER OF INPUT IS A NUMBER FROM 1-9
237  REM
240 X =  ASC ( LEFT$ (A$.1)): IF X < 48 OR (X > 57 AND X <  > 90) THEN  GOTO 50
244  REM
245  REM  CHECK THAT VARIABLE TO BE PLOTTED EXISTS
250 X =  VAL ( LEFT$ (A$.2)): IF X < 0 OR X > NV THEN  GOTO 50
260 Z6 = 0:Z5 = 0
264  REM
265  REM  FIND THE BLANKS IN THE LINE
266  REM
270 A$ = A$ + " ":NK = 0: FOR I = 0 TO 2:NK(I) = 0: NEXT : FOR I = 1 TO  LEN (A$): IF  MID$ (A$.I.1) = " " T
HEN NK = NK + 1:NK(NK - 1) = I
280  NEXT
284  REM
285  REM  THERE MUST BE 3 ARGUMENTS WHEN LINE Y=0 IS BEING PLOTTED
286  REM
290  IF  LEFT$ (A$,4) = "ZERO" AND NK < 2 THEN  GOTO 50
300  IF NK = 1 THEN  GOTO 320
304  REM
305  REM  FIND USER-DEFINED MAXIMUM AND MINIMUM OF VARIABLE TO BE PLOTTED
306  REM
310  FOR I = 1 TO NK - 1:QX(I - 1) =  VAL ( MID$ (A$.NK(I - 1) + 1,NK(I) - NK(I - 1) - 1)): NEXT
314  REM
315  REM  ASSIGN THE PROPER MAXIMA AND MINIMA TO SIMCON GRAPHICS VARIABLES
316  REM
320  IF  LEFT$ (A$.4) <  > "ZERO" THEN I =  VAL ( LEFT$ (A$.2)): GOSUB 780
330  IF NK = 3 THEN  GOTO 370
340  IF NK = 2 THEN  GOTO 360
350 Y1 = ZM(I):Y2 = ZL(I): GOTO 380
360 Y1 = QX(0):Y2 = ZL(I): GOTO 380
370 Y1 = QX(0):Y2 = QX(1): IF  LEFT$ (A$.4) = "ZERO" THEN  GOTO 390
374  REM
375  REM  PRINT THE TRUE MAXIMUM AND MINIMUM
376  REM
380  PRINT "MAX=";ZM(I);" MIN=";ZL(I): GOSUB 730
384  REM
385  REM  DEFINE GRAPH SCALARS
386  REM
390 Z1 = ZX / (NT - ZS):Z2 = 1: IF Y1 <  > 0 OR Y2 <  > 0 THEN Z2 = ZY / (Y1 - Y2)
394  REM
395  REM  PRINT MINIMUM AND MAXIMUM VALUES ON Y AXIS
396  REM
400  IF  LEFT$ (A$,4) <  > "ZERO" THEN  GOSUB 690
404  REM
405  REM  MOVE TO FIRST POINT TO BE PLOTTED
406  REM
410 PP = Z(I,ZS): IF  LEFT$ (A$,4) = "ZERO" THEN PP = 0
420  HPLOT ZW,ZZ - (PP - Y2) * Z2:Z8 = ZS + 1
424  REM
425  REM  PLOT THE INDICATOR
426  REM
430  FOR J = Z8 TO NT:Z8 = J - ZS
440 PP = Z(I,J): IF  LEFT$ (A$,4) = "ZERO" THEN PP = 0
450  HPLOT  TO ZW + Z8 * Z1,ZZ - (PP - Y2) * Z2: NEXT
460  GOTO 50
470  END
480 ZR = 2 *  RND (15) - 1:ZR =  LOG ((1 + ZR) / (1 - ZR)) / 1.82: RETURN
484  REM
485  REM  SUBROUTINE FOR PRINTING GRAPH ONTO PRINTER
486  REM
```

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490 D$ =  CHR$ (4): INPUT "SILENTYPE OR EPSON PRINTER (S/E): ":E$
500  IF E$ = "E" THEN  GOSUB 530: RETURN
510  IF E$ = "S" THEN  GUSUB 610: RETURN
520  RETURN
524  REM
525  REM  PRINTS ON EPSON PRINTER
526  REM
530  INPUT "PLOT TITLE?";T$
540  PRINT D$;"PR#1"
550  PRINT  CHR$ (9);"GI"
560  PRINT D$;"PR#0"
570  RETURN
574  REM
575  REM  GENERAL SUBROUTINE FOR WRITING TEXT ONTO GRAPHICS PAGE.  USES SHAPE TABLE
576  REM
580  ROT= 0: FOR II = 1 TO  LEN (ZN$):II =  ASC ( MID$ (ZN$,II,1)) - 31: IF II < 1 THEN II = 1
590  DRAW II AT X + 6 * II,Y: NEXT : RETURN
594  REM
595  REM  PRINTS GRAPH ONTO APPLE SILENTYPE
596  REM
600 D$ =  CHR$ (4)
610  PRINT : PRINT "-- TYPE '<CTRL-C>' TO INTERRUPT": PRINT "   PRINTOUT"
620  PRINT D$"PR#1"
630  PRINT  CHR$ (20)
640  POKE  - 12524,0: POKE  - 12529,255: POKE  - 12528,7
650  PRINT  CHR$ (17): PRINT D$"PR#0"
660  RETURN
664  REM
665  REM  SUBROUTINE FOR PRINTING FIRST AND LAST TIME STEP ON GRAPH
666  REM
670 X = 0:Y = 145:ZN$ = "0": GOSUB 580
680 X = ZW + ZX - 30:M% = NT:ZN$ =  STR$ (M%): GOSUB 580: RETURN
694  REM
685  REM  SUBROUTINE FOR PRINTING MAXIMUM AND MINIMUM VALUE OF INDICATOR
686  REM
690  HCOLOR= 3:M = Y1
700 ZN$ =  STR$ (M)
710 X = ZW + ZX:AA = AA + 10:Y = AA: GOSUB 580
720 BB = BB - 10:Y = BB:ZN$ =  STR$ (Y2): GOSUB 560: HCOLOR= ZC:ZC = 3: RETURN
724  REM
725  REM  SUBROUTINE FOR CALCULATING THE MINIMUM AND MAXIMUM VALUE OF INDICATORS FROM THE SIMULATION
726  REM
730  HCOLOR= ZC
740 X = 12:Y = YY: IF ZU > 2 THEN X = 120
750  IF ZU > 2 AND ZU < 4 THEN YY =  - 7
760 YY = YY + 10:Y = YY
770  HCOLOR= 3:ZN$ = NA$(I): GOSUB 580:ZU = ZU + 1: RETURN
780 ZL(I) = 0:ZM(I) = 0: FOR J = ZS TO NT
790  IF Z(I,J) > ZM(I) THEN ZM(I) = Z(I,J)
800  IF Z(I,J) < ZL(I) THEN ZL(I) = Z(I,J)
810  NEXT J: RETURN
814  REM
815  REM  SUBROUTINE FOR DISPLAYING INDICATOR VARIABLE DEFINITIONS
816  REM
820  POKE  - 16303,0:FT = 0:FW = 13
830  HOME : FOR IS = FT TO FW
840  PRINT "VAR # ";IS;" = ";NA$(IS)
850  NEXT
860 FT = FT + 14:FW = FW + 14: IF FT = 28 THEN FW = 42
870  PRINT : PRINT "TOUCH ANY KEY TO CONTINUE"
880  IF FW < 42 THEN  PRINT "'/' TO DISPLAY VAR#S ";FT;" TO ";FW
890  GET A$
900  IF A$ <  > "/" OR FW > 42 THEN  GOTO 920
910  GOTO 830
920  VTAB 22: POKE  - 16304,0: RETURN
```

Form 1279-3
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